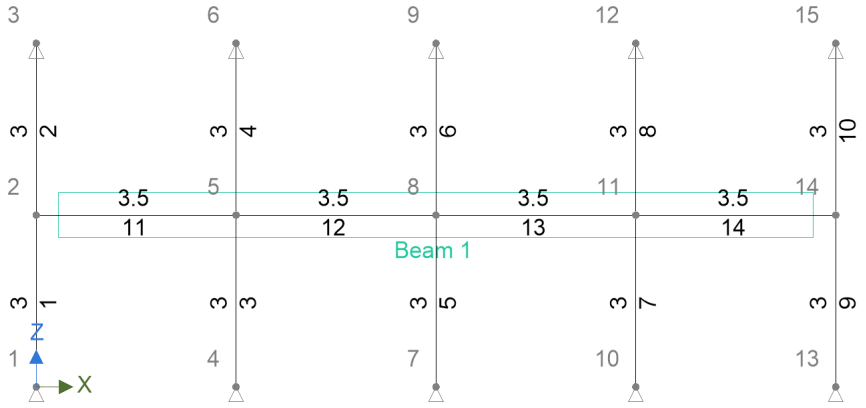
## RC BEAM ANALYSIS & DESIGN (ACI318-2019 (22))

**In accordance with ACI318-2019 (22)**

## ANALYSIS

### Geometry

**Geometry (m)**




### Materials

| Name | Density (kg/m³) | Youngs Modulus kN/mm² | Shear Modulus kN/mm² | Thermal Coefficient °C⁻¹ |
|---|---|---|---|---|
| Concrete Column | 2402.7664096 | 28.9579433 | 12.0658097 | 0.00001 |
| Concrete (2901 150) | 2402.7664096 | 22.512568 | 12.0658097 | 0.00001 |

### Sections

| Name | Area | Moment of inertia | | Shear area parallel to | |
|---|---|---|---|---|---|
| | | Major | Minor | Minor | Major |
| | (cm²) | (cm⁴) | (cm⁴) | (cm²) | (cm²) |
| C30x30 | 900 | 67500 | 67500 | 750 | 750 |
| B30x50 | 1500 | 312500 | 112500 | 1250 | 1250 |

### Nodes

| Node | Co-ordinates | | Freedom | | | Coordinate system | | Spring | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | X | Z | X | Z | Rot. | Name | Angle | X | Z | Rot. |
| | (m) | (m) | | | | | (°) | (kN/m) | (kN/m) | kNm/° |
| 1 | 0 | 0 | Fixed | Fixed | Free | | 0 | 0 | 0 | 0 |
| 2 | 0 | 3 | Free | Free | Free | | 0 | 0 | 0 | 0 |
| 3 | 0 | 6 | Fixed | Fixed | Free | | 0 | 0 | 0 | 0 |
| 4 | 3.5 | 0 | Fixed | Fixed | Free | | 0 | 0 | 0 | 0 |
| 5 | 3.5 | 3 | Free | Free | Free | | 0 | 0 | 0 | 0 |
| 6 | 3.5 | 6 | Fixed | Fixed | Free | | 0 | 0 | 0 | 0 |
| 7 | 7 | 0 | Fixed | Fixed | Free | | 0 | 0 | 0 | 0 |
| 8 | 7 | 3 | Free | Free | Free | | 0 | 0 | 0 | 0 |
| 9 | 7 | 6 | Fixed | Fixed | Free | | 0 | 0 | 0 | 0 |

| Node | Co-ordinates | | Freedom | | | Coordinate system | | Spring | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | X (m) | Z (m) | X | Z | Rot. | Name | Angle (°) | X (kN/m) | Z (kN/m) | Rot. kNm/° |
| 10 | 10.5 | 0 | Fixed | Fixed | Free | | 0 | 0 | 0 | 0 |
| 11 | 10.5 | 3 | Free | Free | Free | | 0 | 0 | 0 | 0 |
| 12 | 10.5 | 6 | Fixed | Fixed | Free | | 0 | 0 | 0 | 0 |
| 13 | 14 | 0 | Fixed | Fixed | Free | | 0 | 0 | 0 | 0 |
| 14 | 14 | 3 | Free | Free | Free | | 0 | 0 | 0 | 0 |
| 15 | 14 | 6 | Fixed | Fixed | Free | | 0 | 0 | 0 | 0 |

**Elements**

| Element | Length (m) | Nodes | | Section | Material | Releases | | | Rotated |
|---|---|---|---|---|---|---|---|---|---|
| | | Start | End | | | Start moment | End moment | Axial | |
| 1 | 3 | 1 | 2 | C30x30 | Concrete Column | Fixed | Fixed | Fixed | |
| 2 | 3 | 2 | 3 | C30x30 | Concrete Column | Fixed | Fixed | Fixed | |
| 3 | 3 | 4 | 5 | C30x30 | Concrete Column | Fixed | Fixed | Fixed | |
| 4 | 3 | 5 | 6 | C30x30 | Concrete Column | Fixed | Fixed | Fixed | |
| 5 | 3 | 7 | 8 | C30x30 | Concrete Column | Fixed | Fixed | Fixed | |
| 6 | 3 | 8 | 9 | C30x30 | Concrete Column | Fixed | Fixed | Fixed | |
| 7 | 3 | 10 | 11 | C30x30 | Concrete Column | Fixed | Fixed | Fixed | |
| 8 | 3 | 11 | 12 | C30x30 | Concrete Column | Fixed | Fixed | Fixed | |
| 9 | 3 | 13 | 14 | C30x30 | Concrete Column | Fixed | Fixed | Fixed | |
| 10 | 3 | 14 | 15 | C30x30 | Concrete Column | Fixed | Fixed | Fixed | |
| 11 | 3.5 | 2 | 5 | B30x50 | Concrete (2901 150) | Fixed | Fixed | Fixed | |
| 12 | 3.5 | 5 | 8 | B30x50 | Concrete (2901 150) | Fixed | Fixed | Fixed | |
| 13 | 3.5 | 8 | 11 | B30x50 | Concrete (2901 150) | Fixed | Fixed | Fixed | |
| 14 | 3.5 | 11 | 14 | B30x50 | Concrete (2901 150) | Fixed | Fixed | Fixed | |

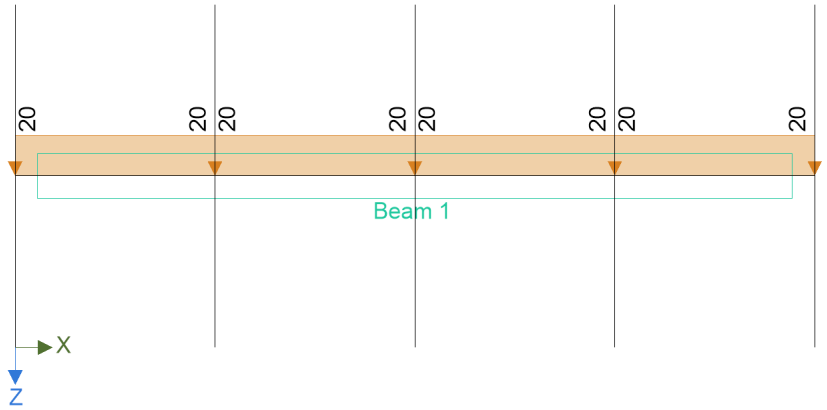
**Members**

| Name | Elements | |
|---|---|---|
| | Start | End |
| Beam 1 | 11 | 14 |

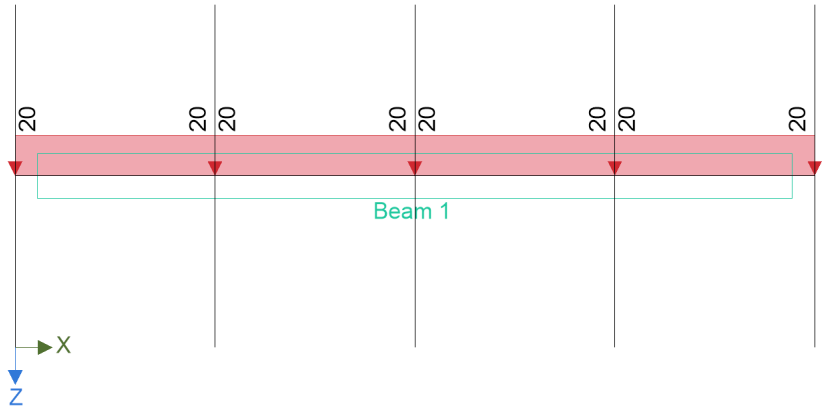
**Loading**

Self weight included

**Dead - Loading (kN/m)**




**Live - Loading (kN/m)**




**Load combination factors**

| Load combination | Self Weight | Dead | Live |
|---|---|---|---|
| 1.4D (Strength) | 1.40 | 1.40 | |
| 1.2D + 1.6L (Strength) | 1.20 | 1.20 | 1.60 |
| 1.0D + 1.0L (Service) | 1.00 | 1.00 | 1.00 |

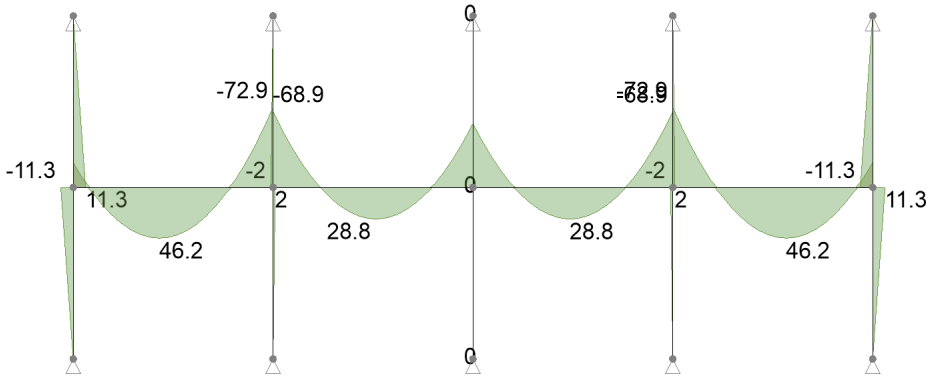
**Member Loads**

| Member | Load case | Load Type | Orientation | Description |
|---|---|---|---|---|
| Beam 1 | Dead | UDL | GlobalZ | 20 kN/m |
| Beam 1 | Live | UDL | GlobalZ | 20 kN/m |

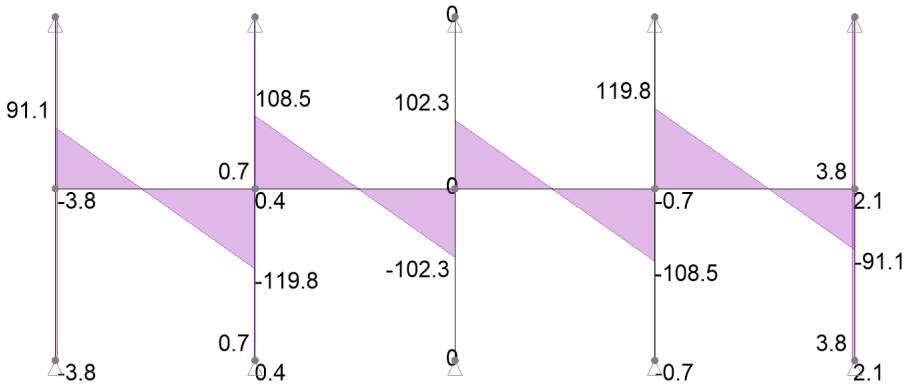
## Results

### Forces

**Strength combinations - Moment envelope (kNm)**




**Strength combinations - Shear envelope (kN)**




**Concrete details**

| | |
|---|---|
| Compressive strength of concrete | $f'_c$ = **20** MPa |
| Density of reinforced concrete | $w_c$ = **24** kN/m$^3$ |
| Concrete type | Normal weight |
| Modulus of elasticity of concrete (cl.19.2.2.1) | $E = (w_c / 1\ lb/ft^3)^{1.5} \times 33\ psi \times (f'_c / 1\ psi)^{0.5}$ = **22513** MPa |
| Strength reduction factor for shear | $\phi_s$ = **0.75** |

**Reinforcement details**

| | |
|---|---|
| Yield strength of reinforcement | $f_y$ = **420** MPa |
| Compression-controlled strain limit (cl.21.2.2.1) | $\varepsilon_{ty} = f_y / E_s$ = **0.00210** |

**Nominal cover to reinforcement**

| | |
|---|---|
| Cover to top reinforcement | $c_{nom\_t}$ = **35** mm |
| Cover to bottom reinforcement | $c_{nom\_b}$ = **35** mm |
| Cover to side reinforcement | $c_{nom\_s}$ = **35** mm |

**Moment adjustment table**

**$R_n / f'_c = M / (0.9 \times f'_c \times b \times 0.9h^2)$**

**$\varepsilon_t = 3 \times ((\beta_1 / (1 - \text{sqrt}(1 - 40/17 \times R_n/f))) - 1) / 1000)$**

**Adjustment is allowed when $\varepsilon_t$ >= 0.0075 up to the maximum allowable specified**

| Location | Iteration No. | $M_{red}$ (kNm) | $R_n / f'_c$ | $\varepsilon_f$ | Adjustment (%) | Final allow. adjustment |
|---|---|---|---|---|---|---|
| **Support 1** | **1** | **19.4** | **0.0579** | **0.0331** | **20.0** | |
| | **2** | **15.5** | **0.0464** | **0.0424** | **20.0** | 20.0 |
| **Support 2** | **1** | **69.7** | **0.2077** | **0.0059** | **0.0** | 0.0 |
| **Support 3** | **1** | **57.9** | **0.1727** | **0.0081** | **8.1** | |
| | **2** | **52.6** | **0.1587** | **0.0092** | **9.2** | 9.2 |
| **Support 4** | **1** | **73.1** | **0.2180** | **0.0054** | **0.0** | 0.0 |
| **Support 5** | **1** | **19.4** | **0.0579** | **0.0331** | **20.0** | |
| | **2** | **15.5** | **0.0464** | **0.0424** | **20.0** | 20.0 |

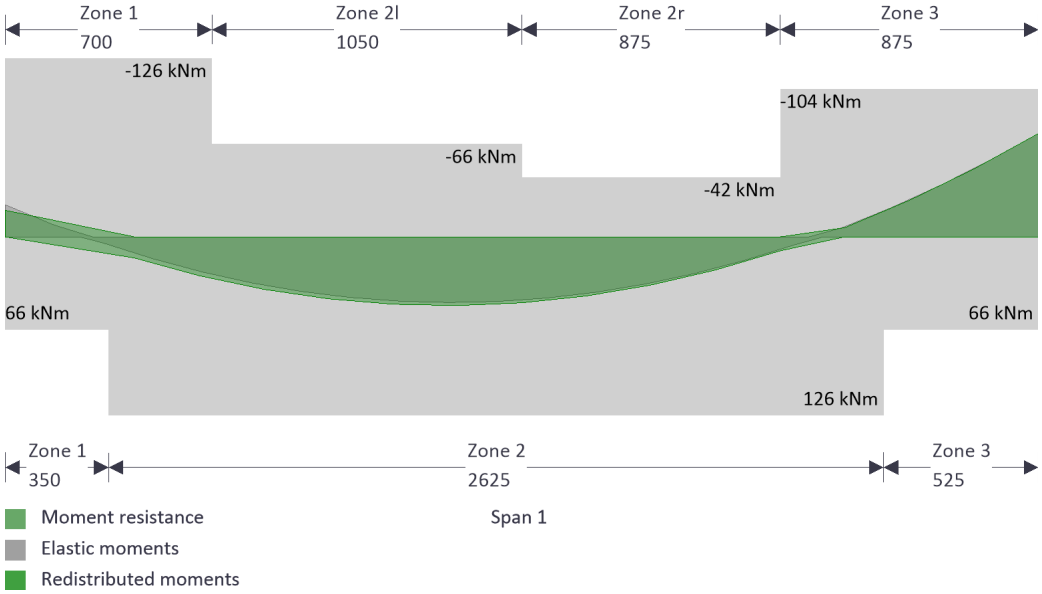
## Beam 1 - Span 1

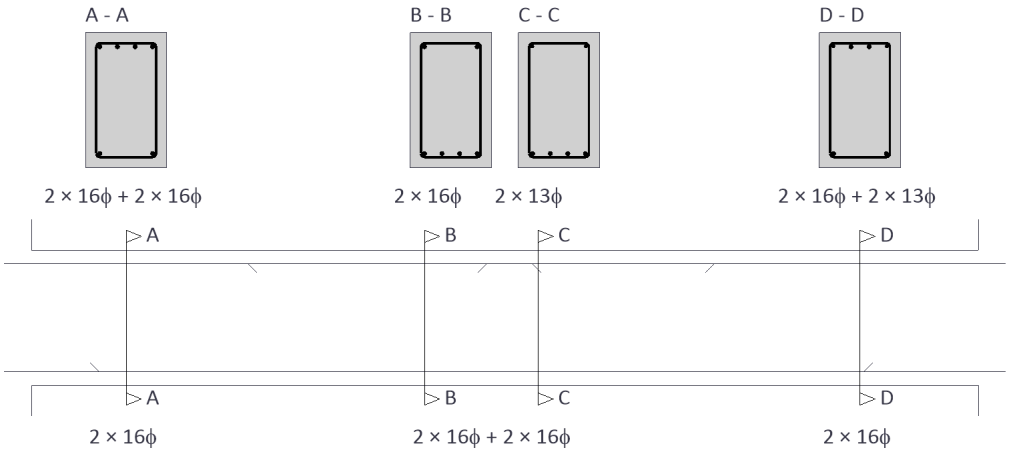
**Rectangular section details**

Section width b = **300** mm

Section depth h = **500** mm

## Moment design






**Zone 1 - Positive moment. Rectangular section in flexure (Section 9.5.2)**

| | |
|---|---|
| Factored bending moment at section | $M_u$ = abs($M_{m1\_s1\_z1\_max\_red}$) = **9.07** kNm |
| Effective depth to tension reinforcement | d = **447.5** mm |
| Tension reinforcement provided | 2 × 16ϕ |
| Area of tension reinforcement provided | $A_{s,prov}$ = **402** mm² |
| Minimum area of reinforcement (cl.9.6.1.2) | $A_{s,min}$ = min(max(3 psi × √(f'c / 1 psi), 200 psi) × b × d / $f_y$, 4/3 × $A_{s,des}$) = **72** mm² |

*PASS - Area of reinforcement provided is greater than minimum area of reinforcement required*

| | |
|---|---|
| Stress block depth factor (cl.22.2.2.4.3) | $\beta_1$ = min(max(0.85 - 0.05 × (f'c - 4 ksi) / 1 ksi, 0.65), 0.85) = **0.85** |
| Depth of equivalent rectangular stress block | a = $A_{s,prov}$ × $f_y$ / (0.85 × f'c × b) = **33** mm |
| Depth to neutral axis | c = a / $\beta_1$ = **39** mm |
| Net tensile strain in extreme tension fibers | $\varepsilon_t$ = 0.003 × ($d_o$ - c) / max(c, 0.001 in) = **0.03146** |

*Net tensile strain in tension controlled zone*

| | |
|---|---|
| Strength reduction factor (cl.21.2.1) | $\phi_f$ = min(max(0.65 + 0.25 × ($\varepsilon_t$ - $\varepsilon_{ty}$) / (0.003), 0.65), 0.9) = **0.90** |
| Nominal moment strength | $M_n$ = $A_{s,prov}$ × $f_y$ × (d - a / 2) = **72.8** kNm |
| Design moment strength | $\phi M_n$ = $M_n$ × $\phi_f$ = **65.5** kNm |

*PASS - Required moment strength is less than design moment strength*

**Flexural cracking**

| | |
|---|---|
| Max. center to center spacing of tension reinf. | $s_{b,max}$ = $s_{bot}$ + $\phi_{m1\_s1\_z1\_b\_L1}$ = **195** mm |
| Service load stress in reinforcement (cl.24.3.2) | $f_s$ = 2/3 × $f_y$ = **280** N/mm² |
| Clear cover of reinforcement | $c_c$ = $c_{nom\_b}$ + $\phi_v$ = **45** mm |
| Maximum allowable bot bar spacing (Table 24.3.2) | $s_{max}$ = min(15in × 40000psi / $f_s$ - 2.5 × $c_c$, 12in × 40000psi / $f_s$) = **264** mm |

*PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing*

**Zone 1 - Negative moment. Rectangular section in flexure (Section 9.5.2)**

| | |
|---|---|
| Factored bending moment at section | $M_u$ = abs($M_{m1\_s1\_z1\_min\_red}$) = **18.72** kNm |
| Effective depth to tension reinforcement | d = **447.5** mm |
| Tension reinforcement provided | 2 × 16ϕ + 2 × 16ϕ |
| Area of tension reinforcement provided | $A_{s,prov}$ = **804** mm² |
| Minimum area of reinforcement (cl.9.6.1.2) | $A_{s,min}$ = min(max(3 psi × √(f'c / 1 psi), 200 psi) × b × d / $f_y$, 4/3 × $A_{s,des}$) = **149** mm² |

*PASS - Area of reinforcement provided is greater than minimum area of reinforcement required*

Stress block depth factor (cl.22.2.2.4.3) $\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\ ksi) / 1\ ksi, 0.65), 0.85) =$ **0.85**

Depth of equivalent rectangular stress block $a = A_{s,prov} \times f_y / (0.85 \times f'_c \times b) =$ **66** mm

Depth to neutral axis $c = a / \beta_1 =$ **78** mm

Net tensile strain in extreme tension fibers $\varepsilon_t = 0.003 \times (d_o - c) / \max(c, 0.001\ in) =$ **0.01423**

*Net tensile strain in tension controlled zone*

Strength reduction factor (cl.21.2.1) $\phi_f = \min(\max(0.65 + 0.25 \times (\varepsilon_t - \varepsilon_{ty}) / (0.003), 0.65), 0.9) =$ **0.90**

Nominal moment strength $M_n = A_{s,prov} \times f_y \times (d - a / 2) =$ **140.0** kNm

Design moment strength $\phi M_n = M_n \times \phi_f =$ **126.0** kNm

*PASS - Required moment strength is less than design moment strength*

**Flexural cracking**

Max. center to center spacing of tension reinf. $s_{t,max} = s_{top} + \phi_{m1\_s1\_z1\_t\_L1} =$ **65** mm

Service load stress in reinforcement (cl.24.3.2) $f_s = 2/3 \times f_y =$ **280** N/mm$^2$

Clear cover of reinforcement $c_c = c_{nom\_t} + \phi_v =$ **45** mm

Maximum allowable top bar spacing (Table 24.3.2) $s_{max} = \min(15in \times 40000psi / f_s - 2.5 \times c_c, 12in \times 40000psi / f_s) =$ **264** mm

*PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing*

**Spacing limits for reinforcement**

Top bar clear spacing $s_{top} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s1\_z1\_v}) + \phi_{m1\_s1\_z1\_t\_L1} \times N_{m1\_s1\_z1\_t\_L1} + \phi_{m1\_s1\_z2l\_t\_L1} \times N_{m1\_s1\_z2l\_t\_L1})) / ((N_{m1\_s1\_z1\_t\_L1} + N_{m1\_s1\_z2l\_t\_L1}) - 1) =$ **49** mm

Min. allowable top bar clear spacing (cl.25.2.1) $s_{top,min} =$ **25** mm

Bottom bar clear spacing $s_{bot} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s1\_z1\_v}) + \phi_{m1\_s1\_z1\_b\_L1} \times N_{m1\_s1\_z1\_b\_L1})) / (N_{m1\_s1\_z1\_b\_L1} - 1) =$ **179** mm

Min. allowable bottom bar clear spacing (cl.25.2.1) $s_{bot,min} =$ **25** mm

*PASS - Actual bar spacing exceeds minimum allowable*

**Zone 2 - Positive moment. Rectangular section in flexure (Section 9.5.2)**

Factored bending moment at section $M_u = abs(M_{m1\_s1\_z2\_max\_red}) =$ **48.42** kNm

Effective depth to tension reinforcement $d =$ **447.5** mm

Tension reinforcement provided $2 \times 16\phi + 2 \times 16\phi$

Area of tension reinforcement provided $A_{s,prov} =$ **804** mm$^2$

Minimum area of reinforcement (cl.9.6.1.2) $A_{s,min} = \min(\max(3\ psi \times \sqrt{(f'_c / 1\ psi)}, 200\ psi) \times b \times d / f_y, 4/3 \times A_{s,des}) =$ **391** mm$^2$

*PASS - Area of reinforcement provided is greater than minimum area of reinforcement required*

Stress block depth factor (cl.22.2.2.4.3) $\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\ ksi) / 1\ ksi, 0.65), 0.85) =$ **0.85**

Depth of equivalent rectangular stress block $a = A_{s,prov} \times f_y / (0.85 \times f'_c \times b) =$ **66** mm

Depth to neutral axis $c = a / \beta_1 =$ **78** mm

Net tensile strain in extreme tension fibers $\varepsilon_t = 0.003 \times (d_o - c) / \max(c, 0.001\ in) =$ **0.01423**

*Net tensile strain in tension controlled zone*

Strength reduction factor (cl.21.2.1) $\phi_f = \min(\max(0.65 + 0.25 \times (\varepsilon_t - \varepsilon_{ty}) / (0.003), 0.65), 0.9) =$ **0.90**

Nominal moment strength $M_n = A_{s,prov} \times f_y \times (d - a / 2) =$ **140.0** kNm

Design moment strength $\phi M_n = M_n \times \phi_f =$ **126.0** kNm

*PASS - Required moment strength is less than design moment strength*

**Flexural cracking**

Max. center to center spacing of tension reinf. $s_{b,max} = s_{bot} + \phi_{m1\_s1\_z2\_b\_L1}$ = **65** mm

Service load stress in reinforcement (cl.24.3.2) $f_s = 2/3 \times f_y$ = **280** N/mm²

Clear cover of reinforcement $c_c = c_{nom\_b} + \phi_v$ = **45** mm

Maximum allowable bot bar spacing (Table 24.3.2) $s_{max} = \min(15in \times 40000psi / f_s - 2.5 \times c_c, 12in \times 40000psi / f_s)$ = **264** mm

*PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing*

**Control of deflections (Section 24.2)**

Concrete density factor $K_w$ = **1.00**

Reinforcement yield strength factor $K_f = 0.4 + f_y / 100000$ psi = **1.01**

Minimum thickness of beam (Table 9.3.1.1) $h_{min} = (L_{m1\_s1} / 18.5) \times K_w \times K_f$ = **191** mm

*PASS - Thickness of beam exceeds minimum thickness*

**Spacing limits for reinforcement**

Top bar clear spacing $s_{top} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s1\_z2\_v}) + \phi_{m1\_s1\_z2r\_t\_L1} \times N_{m1\_s1\_z2r\_t\_L1})) / (N_{m1\_s1\_z2r\_t\_L1} - 1)$ = **186** mm

Min. allowable top bar clear spacing (cl.25.2.1) $s_{top,min}$ = **25** mm

Bottom bar clear spacing $s_{bot} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s1\_z2\_v}) + \phi_{m1\_s1\_z2\_b\_L1} \times N_{m1\_s1\_z2\_b\_L1} + \phi_{m1\_s1\_z1\_b\_L1} \times N_{m1\_s1\_z1\_b\_L1})) / ((N_{m1\_s1\_z2\_b\_L1} + N_{m1\_s1\_z1\_b\_L1}) - 1)$ = **49** mm

Min. allowable bottom bar clear spacing (cl.25.2.1) $s_{bot,min}$ = **25** mm

*PASS - Actual bar spacing exceeds minimum allowable*

**Zone 3 - Negative moment. Rectangular section in flexure (Section 9.5.2)**

Factored bending moment at section $M_u = abs(M_{m1\_s1\_z3\_min\_red})$ = **72.88** kNm

Effective depth to tension reinforcement d = **448.1** mm

Tension reinforcement provided 2 × 16ϕ + 2 × 13ϕ

Area of tension reinforcement provided $A_{s,prov}$ = **655** mm²

Minimum area of reinforcement (cl.9.6.1.2) $A_{s,min} = \min(\max(3 psi \times \sqrt{(f'_c / 1 psi)}, 200 psi) \times b \times d / f_y, 4/3 \times A_{s,des})$ = **441** mm²

*PASS - Area of reinforcement provided is greater than minimum area of reinforcement required*

Stress block depth factor (cl.22.2.2.4.3) $\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4 ksi) / 1 ksi, 0.65), 0.85)$ = **0.85**

Depth of equivalent rectangular stress block $a = A_{s,prov} \times f_y / (0.85 \times f'_c \times b)$ = **54** mm

Depth to neutral axis $c = a / \beta_1$ = **64** mm

Net tensile strain in extreme tension fibers $\varepsilon_t = 0.003 \times (d_o - c) / \max(c, 0.001 in)$ = **0.01817**

*Net tensile strain in tension controlled zone*

Strength reduction factor (cl.21.2.1) $\phi_f = \min(\max(0.65 + 0.25 \times (\varepsilon_t - \varepsilon_{ty}) / (0.003), 0.65), 0.9)$ = **0.90**

Nominal moment strength $M_n = A_{s,prov} \times f_y \times (d - a / 2)$ = **115.9** kNm

Design moment strength $\phi M_n = M_n \times \phi_f$ = **104.3** kNm

*PASS - Required moment strength is less than design moment strength*

**Flexural cracking**

Max. center to center spacing of tension reinf. $s_{t,max} = s_{top} + \phi_{m1\_s1\_z3\_t\_L1}$ = **67** mm

Service load stress in reinforcement (cl.24.3.2) $f_s = 2/3 \times f_y$ = **280** N/mm²

Clear cover of reinforcement $c_c = c_{nom\_t} + \phi_v$ = **45** mm

Maximum allowable top bar spacing (Table 24.3.2) $s_{max} = \min(15in \times 40000psi / f_s - 2.5 \times c_c, 12in \times 40000psi / f_s)$ = **264** mm

*PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing*

**Spacing limits for reinforcement**

Top bar clear spacing — $s_{top} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s1\_z3\_v}) + \phi_{m1\_s1\_z3\_t\_L1} \times N_{m1\_s1\_z3\_t\_L1} + \phi_{m1\_s1\_z2r\_t\_L1} \times N_{m1\_s1\_z2r\_t\_L1})) / ((N_{m1\_s1\_z3\_t\_L1} + N_{m1\_s1\_z2r\_t\_L1}) - 1) =$ **51** mm

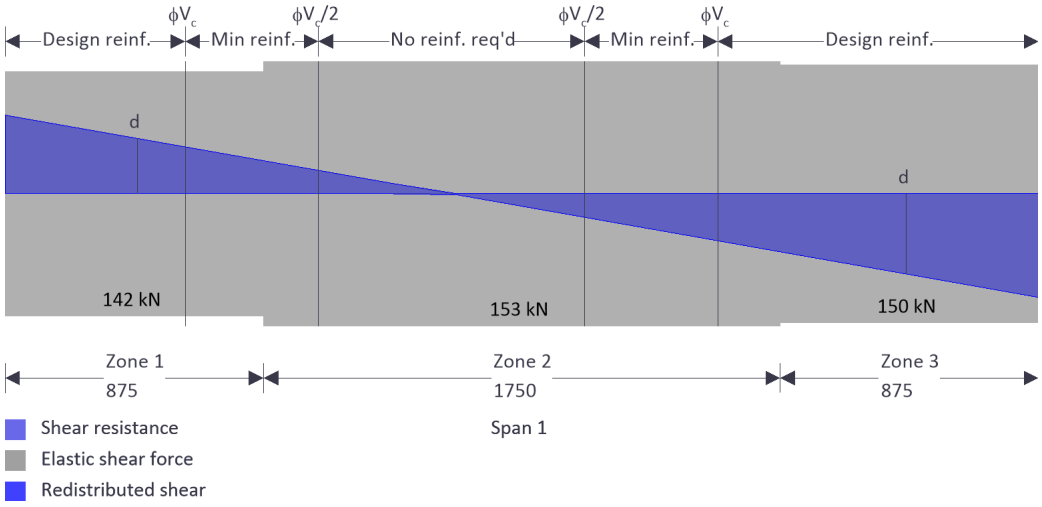
Min. allowable top bar clear spacing (cl.25.2.1) — $s_{top,min} =$ **25** mm

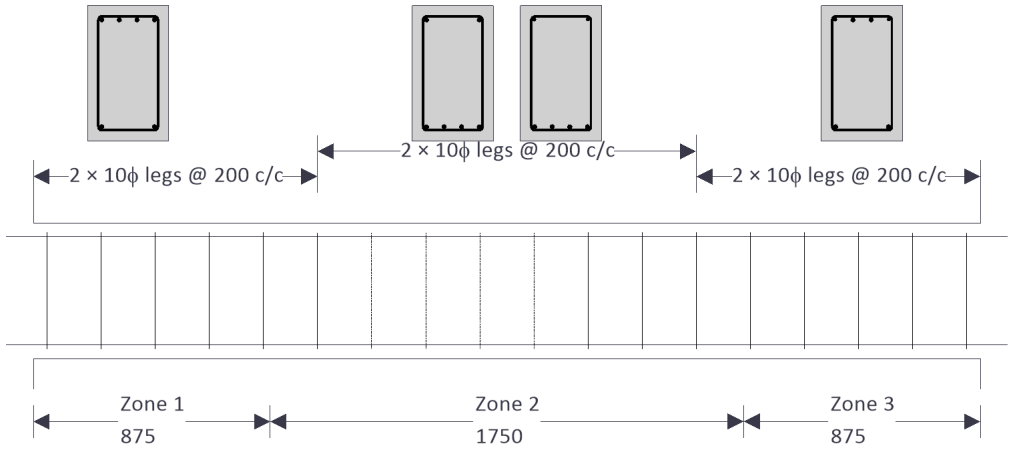
Bottom bar clear spacing — $s_{bot} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s1\_z3\_v}) + \phi_{m1\_s1\_z3\_b\_L1} \times N_{m1\_s1\_z3\_b\_L1})) / (N_{m1\_s1\_z3\_b\_L1} - 1) =$ **179** mm

Min. allowable bottom bar clear spacing (cl.25.2.1) — $s_{bot,min} =$ **25** mm

*PASS - Actual bar spacing exceeds minimum allowable*

**Shear design**




**Rectangular section in shear**

Concrete weight modification factor — $\lambda =$ **1.00**

Location where min. reinf. is req'd ($V_u$ less $\phi V_c$) — Between 610 mm and 2413 mm

Location where no reinf. is req'd ($V_u$ less $\phi V_c$ / 2) — Between 1061 mm and 1962 mm

Maximum reinforcement shear strength — $\phi V_{s,max} = \phi_s \times 8$ psi $\times \sqrt{(\min(f'_c, 10000\text{psi}) / 1\text{ psi})} \times b \times d =$ **299.1** kN

| | |
|---|---|
| Minimum area of shear reinf. (Table 9.6.3.4) | $A_{sv,min}$ = max(50 psi, 0.75 psi × √(f'c / 1 psi)) × b / min($f_y$, 60000 psi) = **250** $mm^2/m$ |

**Zone 1**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**447** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s$ = min(√(2 / (1 + (d / 1 in) / 10)), 1.0) = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **402** $mm^2$ |
| Ratio of longitudinal reinforcement | $\rho_w$ = $A_{st}$ / (b × d) = **0.003** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c$ = $\phi_s$ × min(8 × λ × $(\rho_w)^{1/3}$, 5 × λ) × √(f'c × 1 psi) × b × d = **43.1** kN |
| Design shear force at 447mm from support | $V_u$ = **64.1** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s$ = max($V_u$ - $\phi V_c$, 0 kips) = **21.0** kN |
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des}$ = $\phi V_s$ / ($\phi_s$ × min($f_y$, 60000 psi) × d) = **151** $mm^2/m$ |
| Area of shear reinforcement required | $A_{sv,req}$ = max($A_{sv,min}$, $A_{sv,des}$) = **250** $mm^2/m$ |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |
| Area of shear reinforcement provided | $A_{sv,prov}$ = **713** $mm^2/m$ |
| | *PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required* |
| Maximum longitudinal spacing (Table 9.7.6.2.2) | $s_{vl,max}$ = d / 2 = **223.7** mm |
| | *PASS - longitudinal spacing of stirrups is less than the maximum allowable* |

**Zone 2**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**447** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s$ = min(√(2 / (1 + (d / 1 in) / 10)), 1.0) = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **804** $mm^2$ |
| Ratio of longitudinal reinforcement | $\rho_w$ = $A_{st}$ / (b × d) = **0.006** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c$ = $\phi_s$ × min(8 × λ × $(\rho_w)^{1/3}$, 5 × λ) × √(f'c × 1 psi) × b × d = **54.3** kN |
| Design shear force within zone | $V_u$ = **67.2** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s$ = max($V_u$ - $\phi V_c$, 0 kips) = **12.9** kN |
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des}$ = $\phi V_s$ / ($\phi_s$ × min($f_y$, 60000 psi) × d) = **93** $mm^2/m$ |
| Area of shear reinforcement required | $A_{sv,req}$ = max($A_{sv,min}$, $A_{sv,des}$) = **250** $mm^2/m$ |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |
| Area of shear reinforcement provided | $A_{sv,prov}$ = **713** $mm^2/m$ |
| | *PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required* |
| Maximum longitudinal spacing (Table 9.7.6.2.2) | $s_{vl,max}$ = d / 2 = **223.7** mm |
| | *PASS - longitudinal spacing of stirrups is less than the maximum allowable* |

**Zone 3**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**447** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s$ = min(√(2 / (1 + (d / 1 in) / 10)), 1.0) = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **655** $mm^2$ |
| Ratio of longitudinal reinforcement | $\rho_w$ = $A_{st}$ / (b × d) = **0.005** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c$ = $\phi_s$ × min(8 × λ × $(\rho_w)^{1/3}$, 5 × λ) × √(f'c × 1 psi) × b × d = **50.7** kN |
| Design shear force at 447mm from support | $V_u$ = **93.0** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s$ = max($V_u$ - $\phi V_c$, 0 kips) = **42.2** kN |
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des}$ = $\phi V_s$ / ($\phi_s$ × min($f_y$, 60000 psi) × d) = **304** $mm^2/m$ |
| Area of shear reinforcement required | $A_{sv,req}$ = max($A_{sv,min}$, $A_{sv,des}$) = **304** $mm^2/m$ |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |

Area of shear reinforcement provided $A_{sv,prov}$ = **713** mm²/m

*PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required*

Maximum longitudinal spacing (Table 9.7.6.2.2) $s_{vl,max}$ = d / 2 = **223.7** mm

*PASS - longitudinal spacing of stirrups is less than the maximum allowable*

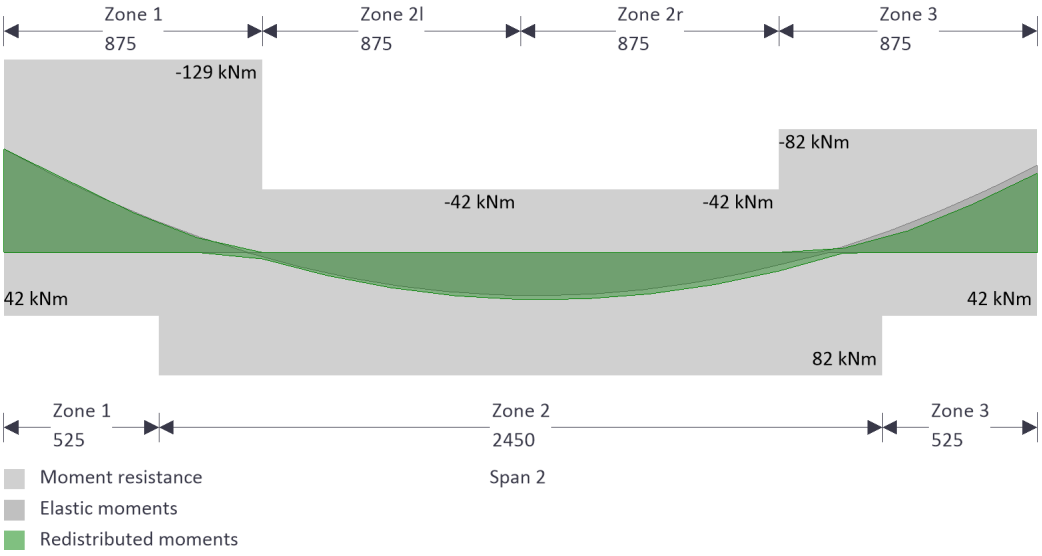
## Beam 1 - Span 2

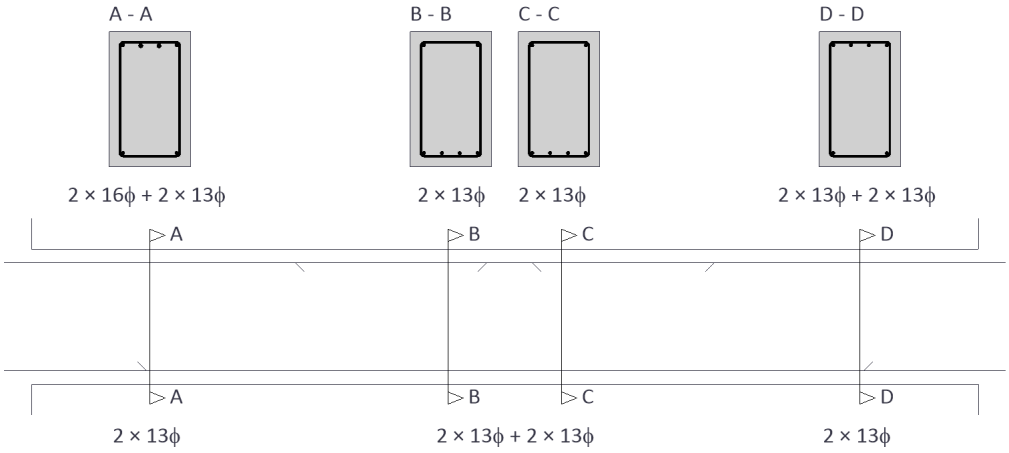
### Rectangular section details

Section width b = **300** mm

Section depth h = **500** mm

### Moment design




### Zone 1 - Negative moment. Rectangular section in flexure (Section 9.5.2)

Factored bending moment at section $M_u$ = abs($M_{m1\_s2\_z1\_min\_red}$) = **68.94** kNm

Effective depth to tension reinforcement d = **446.9** mm

Tension reinforcement provided 2 × 19ϕ + 2 × 13ϕ

Area of tension reinforcement provided $A_{s,prov}$ = **823** mm²

| | |
|---|---|
| Minimum area of reinforcement (cl.9.6.1.2) | $A_{s,min}$ = min(max(3 psi × √(f'c / 1 psi), 200 psi) × b × d / $f_y$, 4/3 × $A_{s,des}$) = **440** $mm^2$ |
| | *PASS - Area of reinforcement provided is greater than minimum area of reinforcement required* |
| Stress block depth factor (cl.22.2.2.4.3) | $\beta_1$ = min(max(0.85 - 0.05 × (f'c - 4 ksi) / 1 ksi, 0.65), 0.85) = **0.85** |
| Depth of equivalent rectangular stress block | a = $A_{s,prov}$ × $f_y$ / (0.85 × f'c × b) = **68** mm |
| Depth to neutral axis | c = a / $\beta_1$ = **80** mm |
| Net tensile strain in extreme tension fibers | $\varepsilon_t$ = 0.003 × ($d_o$ - c) / max(c, 0.001 in) = **0.01381** |
| | *Net tensile strain in tension controlled zone* |
| Strength reduction factor (cl.21.2.1) | $\phi_f$ = min(max(0.65 + 0.25 × ($\varepsilon_t$ - $\varepsilon_{ty}$) / (0.003), 0.65), 0.9) = **0.90** |
| Nominal moment strength | $M_n$ = $A_{s,prov}$ × $f_y$ × (d - a / 2) = **142.8** kNm |
| Design moment strength | $\phi M_n$ = $M_n$ × $\phi_f$ = **128.6** kNm |
| | *PASS - Required moment strength is less than design moment strength* |
| **Flexural cracking** | |
| Max. center to center spacing of tension reinf. | $s_{t,max}$ = $s_{top}$ + $\phi_{m1\_s2\_z1\_t\_L1}$ = **65** mm |
| Service load stress in reinforcement (cl.24.3.2) | $f_s$ = 2/3 × $f_y$ = **280** $N/mm^2$ |
| Clear cover of reinforcement | $c_c$ = $c_{nom\_t}$ + $\phi_v$ = **45** mm |
| Maximum allowable top bar spacing (Table 24.3.2) | $s_{max}$ = min(15in × 40000psi / $f_s$ - 2.5 × $c_c$, 12in × 40000psi / $f_s$) = **264** mm |
| | *PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing* |
| **Spacing limits for reinforcement** | |
| Top bar clear spacing | $s_{top}$ = (b - (2 × ($c_{nom\_s}$ + $\phi_{m1\_s2\_z1\_v}$) + $\phi_{m1\_s2\_z1\_t\_L1}$ × $N_{m1\_s2\_z1\_t\_L1}$ + $\phi_{m1\_s2\_z2l\_t\_L1}$ × $N_{m1\_s2\_z2l\_t\_L1}$)) / (($N_{m1\_s2\_z1\_t\_L1}$ + $N_{m1\_s2\_z2l\_t\_L1}$) - 1) = **51** mm |
| Min. allowable top bar clear spacing (cl.25.2.1) | $s_{top,min}$ = **25** mm |
| Bottom bar clear spacing | $s_{bot}$ = (b - (2 × ($c_{nom\_s}$ + $\phi_{m1\_s2\_z1\_v}$) + $\phi_{m1\_s2\_z1\_b\_L1}$ × $N_{m1\_s2\_z1\_b\_L1}$)) / ($N_{m1\_s2\_z1\_b\_L1}$ - 1) = **186** mm |
| Min. allowable bottom bar clear spacing (cl.25.2.1) | $s_{bot,min}$ = **25** mm |
| | *PASS - Actual bar spacing exceeds minimum allowable* |
| **Zone 2 - Positive moment. Rectangular section in flexure (Section 9.5.2)** | |
| Factored bending moment at section | $M_u$ = abs($M_{m1\_s2\_z2\_max\_red}$) = **31.54** kNm |
| Effective depth to tension reinforcement | d = **449.1** mm |
| Tension reinforcement provided | 2 × 13$\phi$ + 2 × 13$\phi$ |
| Area of tension reinforcement provided | $A_{s,prov}$ = **507** $mm^2$ |
| Minimum area of reinforcement (cl.9.6.1.2) | $A_{s,min}$ = min(max(3 psi × √(f'c / 1 psi), 200 psi) × b × d / $f_y$, 4/3 × $A_{s,des}$) = **251** $mm^2$ |
| | *PASS - Area of reinforcement provided is greater than minimum area of reinforcement required* |
| Stress block depth factor (cl.22.2.2.4.3) | $\beta_1$ = min(max(0.85 - 0.05 × (f'c - 4 ksi) / 1 ksi, 0.65), 0.85) = **0.85** |
| Depth of equivalent rectangular stress block | a = $A_{s,prov}$ × $f_y$ / (0.85 × f'c × b) = **42** mm |
| Depth to neutral axis | c = a / $\beta_1$ = **49** mm |
| Net tensile strain in extreme tension fibers | $\varepsilon_t$ = 0.003 × ($d_o$ - c) / max(c, 0.001 in) = **0.02445** |
| | *Net tensile strain in tension controlled zone* |
| Strength reduction factor (cl.21.2.1) | $\phi_f$ = min(max(0.65 + 0.25 × ($\varepsilon_t$ - $\varepsilon_{ty}$) / (0.003), 0.65), 0.9) = **0.90** |
| Nominal moment strength | $M_n$ = $A_{s,prov}$ × $f_y$ × (d - a / 2) = **91.1** kNm |
| Design moment strength | $\phi M_n$ = $M_n$ × $\phi_f$ = **82.0** kNm |

*PASS - Required moment strength is less than design moment strength*

**Flexural cracking**

Max. center to center spacing of tension reinf. $s_{b,max} = s_{bot} + \phi_{m1\_s2\_z2\_b\_L1}$ = **66** mm

Service load stress in reinforcement (cl.24.3.2) $f_s = 2/3 \times f_y$ = **280** N/mm²

Clear cover of reinforcement $c_c = c_{nom\_b} + \phi_v$ = **45** mm

Maximum allowable bot bar spacing (Table 24.3.2) $s_{max}$ = min(15in × 40000psi / $f_s$ - 2.5 × $c_c$, 12in × 40000psi / $f_s$) = **264** mm

*PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing*

**Control of deflections (Section 24.2)**

Concrete density factor $K_w$ = **1.00**

Reinforcement yield strength factor $K_f = 0.4 + f_y / 100000$ psi = **1.01**

Minimum thickness of beam (Table 9.3.1.1) $h_{min} = (L_{m1\_s2} / 21.0) \times K_w \times K_f$ = **168** mm

*PASS - Thickness of beam exceeds minimum thickness*

**Spacing limits for reinforcement**

Top bar clear spacing $s_{top} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s2\_z2\_v}) + \phi_{m1\_s2\_z2r\_t\_L1} \times N_{m1\_s2\_z2r\_t\_L1})) / (N_{m1\_s2\_z2r\_t\_L1} - 1)$ = **186** mm

Min. allowable top bar clear spacing (cl.25.2.1) $s_{top,min}$ = **25** mm

Bottom bar clear spacing $s_{bot} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s2\_z2\_v}) + \phi_{m1\_s2\_z2\_b\_L1} \times N_{m1\_s2\_z2\_b\_L1} + \phi_{m1\_s2\_z1\_b\_L1} \times N_{m1\_s2\_z1\_b\_L1})) / ((N_{m1\_s2\_z2\_b\_L1} + N_{m1\_s2\_z1\_b\_L1}) - 1)$ = **53** mm

Min. allowable bottom bar clear spacing (cl.25.2.1) $s_{bot,min}$ = **25** mm

*PASS - Actual bar spacing exceeds minimum allowable*

**Zone 3 - Negative moment. Rectangular section in flexure (Section 9.5.2)**

Factored bending moment at section $M_u = abs(M_{m1\_s2\_z3\_min\_red})$ = **52.78** kNm

Effective depth to tension reinforcement d = **449.1** mm

Tension reinforcement provided 2 × 13ϕ + 2 × 13ϕ

Area of tension reinforcement provided $A_{s,prov}$ = **507** mm²

Minimum area of reinforcement (cl.9.6.1.2) $A_{s,min}$ = min(max(3 psi × √(f'c / 1 psi), 200 psi) × b × d / $f_y$, 4/3 × $A_{s,des}$) = **425** mm²

*PASS - Area of reinforcement provided is greater than minimum area of reinforcement required*

Stress block depth factor (cl.22.2.2.4.3) $\beta_1$ = min(max(0.85 - 0.05 × (f'c - 4 ksi) / 1 ksi, 0.65), 0.85) = **0.85**

Depth of equivalent rectangular stress block a = $A_{s,prov} \times f_y$ / (0.85 × f'c × b) = **42** mm

Depth to neutral axis c = a / $\beta_1$ = **49** mm

Net tensile strain in extreme tension fibers $\varepsilon_t = 0.003 \times (d_o - c) / max(c, 0.001$ in) = **0.02445**

*Net tensile strain in tension controlled zone*

Strength reduction factor (cl.21.2.1) $\phi_f$ = min(max(0.65 + 0.25 × ($\varepsilon_t$ - $\varepsilon_{ty}$) / (0.003), 0.65), 0.9) = **0.90**

Nominal moment strength $M_n = A_{s,prov} \times f_y \times (d - a / 2)$ = **91.1** kNm

Design moment strength $\phi M_n = M_n \times \phi_f$ = **82.0** kNm

*PASS - Required moment strength is less than design moment strength*

**Flexural cracking**

Max. center to center spacing of tension reinf. $s_{t,max} = s_{top} + \phi_{m1\_s2\_z3\_t\_L1}$ = **66** mm

Service load stress in reinforcement (cl.24.3.2) $f_s = 2/3 \times f_y$ = **280** N/mm²

Clear cover of reinforcement $c_c = c_{nom\_t} + \phi_v$ = **45** mm

Maximum allowable top bar spacing (Table 24.3.2) $s_{max}$ = min(15in × 40000psi / $f_s$ - 2.5 × $c_c$, 12in × 40000psi / $f_s$) = **264** mm

*PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing*

**Spacing limits for reinforcement**

Top bar clear spacing — $s_{top} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s2\_z3\_v}) + \phi_{m1\_s2\_z3\_t\_L1} \times N_{m1\_s2\_z3\_t\_L1} + \phi_{m1\_s2\_z2r\_t\_L1} \times N_{m1\_s2\_z2r\_t\_L1})) / ((N_{m1\_s2\_z3\_t\_L1} + N_{m1\_s2\_z2r\_t\_L1}) - 1) =$ **53** mm

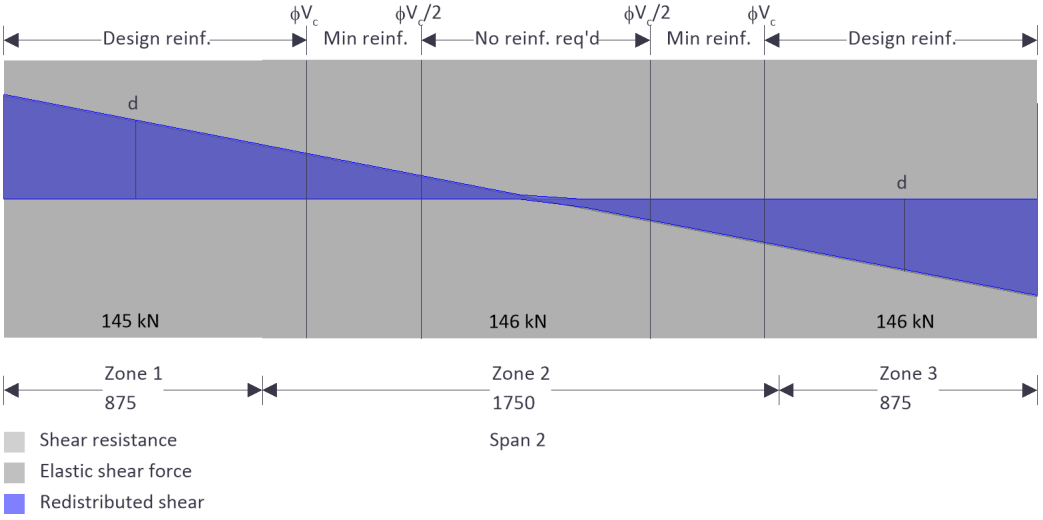
Min. allowable top bar clear spacing (cl.25.2.1) — $s_{top,min} =$ **25** mm

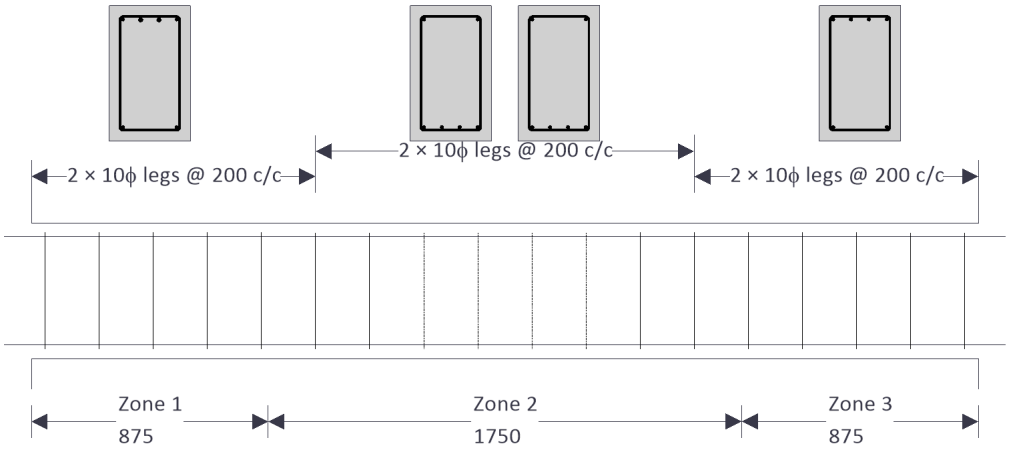
Bottom bar clear spacing — $s_{bot} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s2\_z3\_v}) + \phi_{m1\_s2\_z3\_b\_L1} \times N_{m1\_s2\_z3\_b\_L1})) / (N_{m1\_s2\_z3\_b\_L1} - 1) =$ **186** mm

Min. allowable bottom bar clear spacing (cl.25.2.1) — $s_{bot,min} =$ **25** mm

*PASS - Actual bar spacing exceeds minimum allowable*

**Shear design**




**Rectangular section in shear**

Concrete weight modification factor — $\lambda =$ **1.00**

Location where min. reinf. is req'd ($V_u$ less $\phi V_c$) — Between 1026 mm and 2576 mm

Location where no reinf. is req'd ($V_u$ less $\phi V_c$ / 2) — Between 1414 mm and 2189 mm

Maximum reinforcement shear strength — $\phi V_{s,max} = \phi_s \times 8$ psi $\times \sqrt{(\min(f'_c, 10000\text{psi}) / 1\text{ psi})} \times b \times d =$ **300.2** kN

| | |
|---|---|
| Minimum area of shear reinf. (Table 9.6.3.4) | $A_{sv,min}$ = max(50 psi, 0.75 psi × √(f'c / 1 psi)) × b / min($f_y$, 60000 psi) = **250** $mm^2/m$ |

**Zone 1**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**447** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s$ = min(√(2 / (1 + (d / 1 in) / 10)), 1.0) = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **507** $mm^2$ |
| Ratio of longitudinal reinforcement | $\rho_w$ = $A_{st}$ / (b × d) = **0.004** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c$ = $\phi_s$ × min(8 × λ × $(\rho_w)^{1/3}$, 5 × λ) × √(f'c × 1 psi) × b × d = **46.5** kN |
| Design shear force at 447mm from support | $V_u$ = **83.1** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s$ = max($V_u$ - $\phi V_c$, 0 kips) = **36.6** kN |
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des}$ = $\phi V_s$ / ($\phi_s$ × min($f_y$, 60000 psi) × d) = **264** $mm^2/m$ |
| Area of shear reinforcement required | $A_{sv,req}$ = max($A_{sv,min}$, $A_{sv,des}$) = **264** $mm^2/m$ |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |
| Area of shear reinforcement provided | $A_{sv,prov}$ = **713** $mm^2/m$ |
| | *PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required* |
| Maximum longitudinal spacing (Table 9.7.6.2.2) | $s_{vl,max}$ = d / 2 = **223.5** mm |
| | *PASS - longitudinal spacing of stirrups is less than the maximum allowable* |

**Zone 2**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**449** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s$ = min(√(2 / (1 + (d / 1 in) / 10)), 1.0) = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **507** $mm^2$ |
| Ratio of longitudinal reinforcement | $\rho_w$ = $A_{st}$ / (b × d) = **0.004** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c$ = $\phi_s$ × min(8 × λ × $(\rho_w)^{1/3}$, 5 × λ) × √(f'c × 1 psi) × b × d = **46.7** kN |
| Design shear force within zone | $V_u$ = **57.3** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s$ = max($V_u$ - $\phi V_c$, 0 kips) = **10.6** kN |
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des}$ = $\phi V_s$ / ($\phi_s$ × min($f_y$, 60000 psi) × d) = **76** $mm^2/m$ |
| Area of shear reinforcement required | $A_{sv,req}$ = max($A_{sv,min}$, $A_{sv,des}$) = **250** $mm^2/m$ |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |
| Area of shear reinforcement provided | $A_{sv,prov}$ = **713** $mm^2/m$ |
| | *PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required* |
| Maximum longitudinal spacing (Table 9.7.6.2.2) | $s_{vl,max}$ = d / 2 = **224.6** mm |
| | *PASS - longitudinal spacing of stirrups is less than the maximum allowable* |

**Zone 3**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**449** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s$ = min(√(2 / (1 + (d / 1 in) / 10)), 1.0) = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **507** $mm^2$ |
| Ratio of longitudinal reinforcement | $\rho_w$ = $A_{st}$ / (b × d) = **0.004** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c$ = $\phi_s$ × min(8 × λ × $(\rho_w)^{1/3}$, 5 × λ) × √(f'c × 1 psi) × b × d = **46.7** kN |
| Design shear force at 449mm from support | $V_u$ = **75.3** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s$ = max($V_u$ - $\phi V_c$, 0 kips) = **28.6** kN |
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des}$ = $\phi V_s$ / ($\phi_s$ × min($f_y$, 60000 psi) × d) = **205** $mm^2/m$ |
| Area of shear reinforcement required | $A_{sv,req}$ = max($A_{sv,min}$, $A_{sv,des}$) = **250** $mm^2/m$ |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |

Area of shear reinforcement provided $A_{sv,prov}$ = **713** mm²/m

*PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required*

Maximum longitudinal spacing (Table 9.7.6.2.2) $s_{vl,max}$ = d / 2 = **224.6** mm

*PASS - longitudinal spacing of stirrups is less than the maximum allowable*

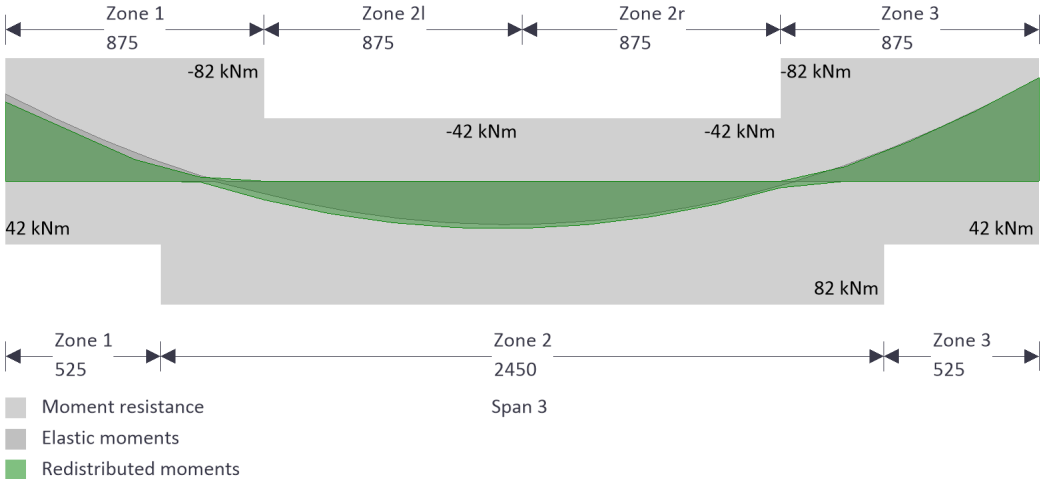
## Beam 1 - Span 3

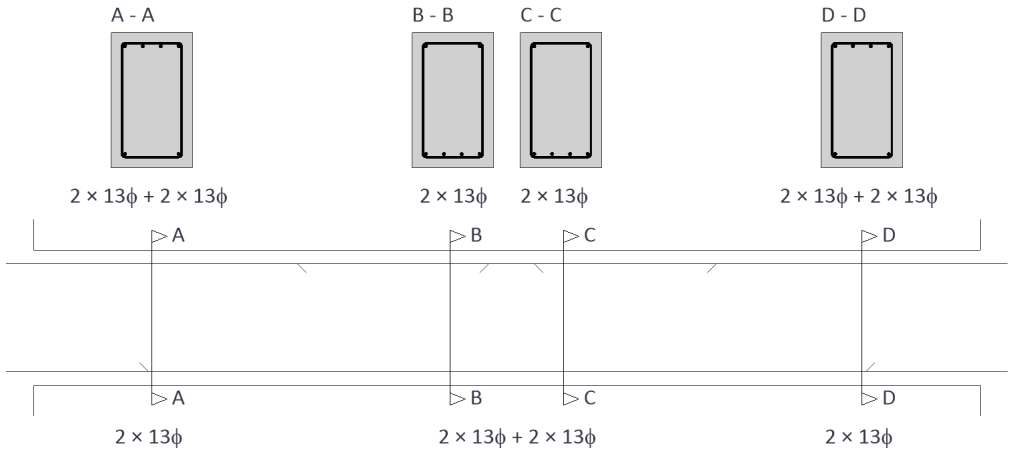
### Rectangular section details

Section width b = **300** mm

Section depth h = **500** mm

### Moment design




### Zone 1 - Negative moment. Rectangular section in flexure (Section 9.5.2)

Factored bending moment at section $M_u$ = abs($M_{m1\_s3\_z1\_min\_red}$) = **52.78** kNm

Effective depth to tension reinforcement d = **449.1** mm

Tension reinforcement provided 2 × 13ϕ + 2 × 13ϕ

Area of tension reinforcement provided $A_{s,prov}$ = **507** mm²

Minimum area of reinforcement (cl.9.6.1.2) $A_{s,min}$ = min(max(3 psi × √(f'c / 1 psi), 200 psi) × b × d / $f_y$, 4/3 × $A_{s,des}$) = **425** mm²

*PASS - Area of reinforcement provided is greater than minimum area of reinforcement required*

Stress block depth factor (cl.22.2.2.4.3) $\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\ ksi) / 1\ ksi, 0.65), 0.85) =$ **0.85**

Depth of equivalent rectangular stress block $a = A_{s,prov} \times f_y / (0.85 \times f'_c \times b) =$ **42** mm

Depth to neutral axis $c = a / \beta_1 =$ **49** mm

Net tensile strain in extreme tension fibers $\varepsilon_t = 0.003 \times (d_o - c) / \max(c, 0.001\ in) =$ **0.02445**

*Net tensile strain in tension controlled zone*

Strength reduction factor (cl.21.2.1) $\phi_f = \min(\max(0.65 + 0.25 \times (\varepsilon_t - \varepsilon_{ty}) / (0.003), 0.65), 0.9) =$ **0.90**

Nominal moment strength $M_n = A_{s,prov} \times f_y \times (d - a / 2) =$ **91.1** kNm

Design moment strength $\phi M_n = M_n \times \phi_f =$ **82.0** kNm

*PASS - Required moment strength is less than design moment strength*

**Flexural cracking**

Max. center to center spacing of tension reinf. $s_{t,max} = s_{top} + \phi_{m1\_s3\_z1\_t\_L1} =$ **66** mm

Service load stress in reinforcement (cl.24.3.2) $f_s = 2/3 \times f_y =$ **280** N/mm$^2$

Clear cover of reinforcement $c_c = c_{nom\_t} + \phi_v =$ **45** mm

Maximum allowable top bar spacing (Table 24.3.2) $s_{max} = \min(15in \times 40000psi / f_s - 2.5 \times c_c, 12in \times 40000psi / f_s) =$ **264** mm

*PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing*

**Spacing limits for reinforcement**

Top bar clear spacing $s_{top} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s3\_z1\_v}) + \phi_{m1\_s3\_z1\_t\_L1} \times N_{m1\_s3\_z1\_t\_L1} + \phi_{m1\_s3\_z2l\_t\_L1} \times N_{m1\_s3\_z2l\_t\_L1})) / ((N_{m1\_s3\_z1\_t\_L1} + N_{m1\_s3\_z2l\_t\_L1}) - 1) =$ **53** mm

Min. allowable top bar clear spacing (cl.25.2.1) $s_{top,min} =$ **25** mm

Bottom bar clear spacing $s_{bot} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s3\_z1\_v}) + \phi_{m1\_s3\_z1\_b\_L1} \times N_{m1\_s3\_z1\_b\_L1})) / (N_{m1\_s3\_z1\_b\_L1} - 1) =$ **186** mm

Min. allowable bottom bar clear spacing (cl.25.2.1) $s_{bot,min} =$ **25** mm

*PASS - Actual bar spacing exceeds minimum allowable*

**Zone 2 - Positive moment. Rectangular section in flexure (Section 9.5.2)**

Factored bending moment at section $M_u = abs(M_{m1\_s3\_z2\_max\_red}) =$ **31.54** kNm

Effective depth to tension reinforcement $d =$ **449.1** mm

Tension reinforcement provided $2 \times 13\phi + 2 \times 13\phi$

Area of tension reinforcement provided $A_{s,prov} =$ **507** mm$^2$

Minimum area of reinforcement (cl.9.6.1.2) $A_{s,min} = \min(\max(3\ psi \times \sqrt{(f'_c / 1\ psi)}, 200\ psi) \times b \times d / f_y, 4/3 \times A_{s,des}) =$ **251** mm$^2$

*PASS - Area of reinforcement provided is greater than minimum area of reinforcement required*

Stress block depth factor (cl.22.2.2.4.3) $\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\ ksi) / 1\ ksi, 0.65), 0.85) =$ **0.85**

Depth of equivalent rectangular stress block $a = A_{s,prov} \times f_y / (0.85 \times f'_c \times b) =$ **42** mm

Depth to neutral axis $c = a / \beta_1 =$ **49** mm

Net tensile strain in extreme tension fibers $\varepsilon_t = 0.003 \times (d_o - c) / \max(c, 0.001\ in) =$ **0.02445**

*Net tensile strain in tension controlled zone*

Strength reduction factor (cl.21.2.1) $\phi_f = \min(\max(0.65 + 0.25 \times (\varepsilon_t - \varepsilon_{ty}) / (0.003), 0.65), 0.9) =$ **0.90**

Nominal moment strength $M_n = A_{s,prov} \times f_y \times (d - a / 2) =$ **91.1** kNm

Design moment strength $\phi M_n = M_n \times \phi_f =$ **82.0** kNm

*PASS - Required moment strength is less than design moment strength*

**Flexural cracking**

Max. center to center spacing of tension reinf. $s_{b,max} = s_{bot} + \phi_{m1\_s3\_z2\_b\_L1}$ = **66** mm

Service load stress in reinforcement (cl.24.3.2) $f_s = 2/3 \times f_y$ = **280** N/mm²

Clear cover of reinforcement $c_c = c_{nom\_b} + \phi_v$ = **45** mm

Maximum allowable bot bar spacing (Table 24.3.2) $s_{max} = \min(15in \times 40000psi / f_s - 2.5 \times c_c, 12in \times 40000psi / f_s)$ = **264** mm

*PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing*

**Control of deflections (Section 24.2)**

Concrete density factor $K_w$ = **1.00**

Reinforcement yield strength factor $K_f = 0.4 + f_y / 100000\ psi$ = **1.01**

Minimum thickness of beam (Table 9.3.1.1) $h_{min} = (L_{m1\_s3} / 21.0) \times K_w \times K_f$ = **168** mm

*PASS - Thickness of beam exceeds minimum thickness*

**Spacing limits for reinforcement**

Top bar clear spacing $s_{top} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s3\_z2\_v}) + \phi_{m1\_s3\_z2r\_t\_L1} \times N_{m1\_s3\_z2r\_t\_L1})) / (N_{m1\_s3\_z2r\_t\_L1} - 1)$ = **186** mm

Min. allowable top bar clear spacing (cl.25.2.1) $s_{top,min}$ = **25** mm

Bottom bar clear spacing $s_{bot} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s3\_z2\_v}) + \phi_{m1\_s3\_z2\_b\_L1} \times N_{m1\_s3\_z2\_b\_L1} + \phi_{m1\_s3\_z1\_b\_L1} \times N_{m1\_s3\_z1\_b\_L1})) / ((N_{m1\_s3\_z2\_b\_L1} + N_{m1\_s3\_z1\_b\_L1}) - 1)$ = **53** mm

Min. allowable bottom bar clear spacing (cl.25.2.1) $s_{bot,min}$ = **25** mm

*PASS - Actual bar spacing exceeds minimum allowable*

**Zone 3 - Negative moment. Rectangular section in flexure (Section 9.5.2)**

Factored bending moment at section $M_u = abs(M_{m1\_s3\_z3\_min\_red})$ = **68.94** kNm

Effective depth to tension reinforcement d = **449.1** mm

Tension reinforcement provided 2 × 13ϕ + 2 × 13ϕ

Area of tension reinforcement provided $A_{s,prov}$ = **507** mm²

Minimum area of reinforcement (cl.9.6.1.2) $A_{s,min} = \max(3\ psi \times \sqrt{(f'_c / 1\ psi)}, 200\ psi) \times b \times d / f_y$ = **442** mm²

*PASS - Area of reinforcement provided is greater than minimum area of reinforcement required*

Stress block depth factor (cl.22.2.2.4.3) $\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\ ksi) / 1\ ksi, 0.65), 0.85)$ = **0.85**

Depth of equivalent rectangular stress block $a = A_{s,prov} \times f_y / (0.85 \times f'_c \times b)$ = **42** mm

Depth to neutral axis $c = a / \beta_1$ = **49** mm

Net tensile strain in extreme tension fibers $\varepsilon_t = 0.003 \times (d_o - c) / \max(c, 0.001\ in)$ = **0.02445**

*Net tensile strain in tension controlled zone*

Strength reduction factor (cl.21.2.1) $\phi_f = \min(\max(0.65 + 0.25 \times (\varepsilon_t - \varepsilon_{ty}) / (0.003), 0.65), 0.9)$ = **0.90**

Nominal moment strength $M_n = A_{s,prov} \times f_y \times (d - a / 2)$ = **91.1** kNm

Design moment strength $\phi M_n = M_n \times \phi_f$ = **82.0** kNm

*PASS - Required moment strength is less than design moment strength*

**Flexural cracking**

Max. center to center spacing of tension reinf. $s_{t,max} = s_{top} + \phi_{m1\_s3\_z3\_t\_L1}$ = **66** mm

Service load stress in reinforcement (cl.24.3.2) $f_s = 2/3 \times f_y$ = **280** N/mm²

Clear cover of reinforcement $c_c = c_{nom\_t} + \phi_v$ = **45** mm

Maximum allowable top bar spacing (Table 24.3.2) $s_{max} = \min(15in \times 40000psi / f_s - 2.5 \times c_c, 12in \times 40000psi / f_s)$ = **264** mm

*PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing*

**Spacing limits for reinforcement**

Top bar clear spacing — $s_{top} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s3\_z3\_v}) + \phi_{m1\_s3\_z3\_t\_L1} \times N_{m1\_s3\_z3\_t\_L1} + \phi_{m1\_s3\_z2r\_t\_L1} \times N_{m1\_s3\_z2r\_t\_L1})) / ((N_{m1\_s3\_z3\_t\_L1} + N_{m1\_s3\_z2r\_t\_L1}) - 1) =$ **53** mm

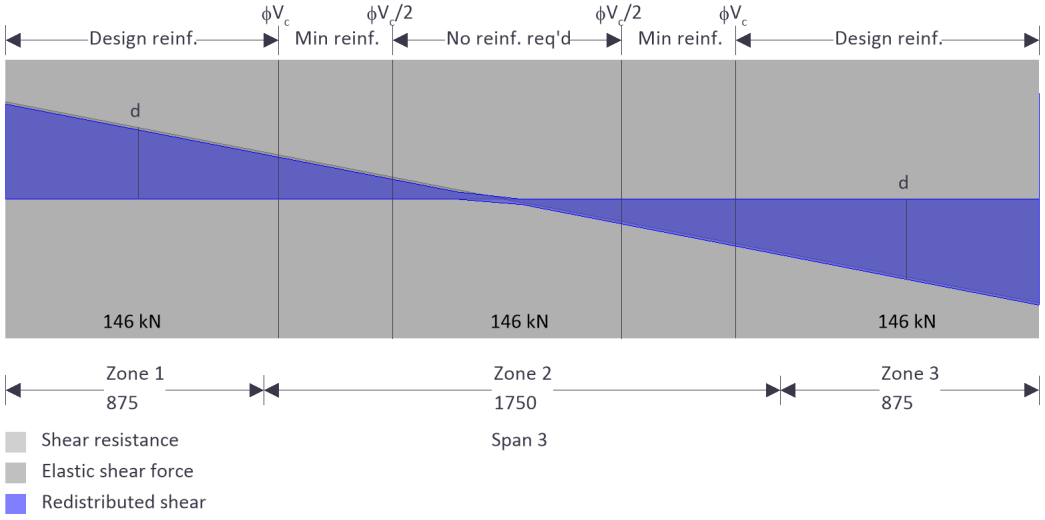
Min. allowable top bar clear spacing (cl.25.2.1) — $s_{top,min} =$ **25** mm

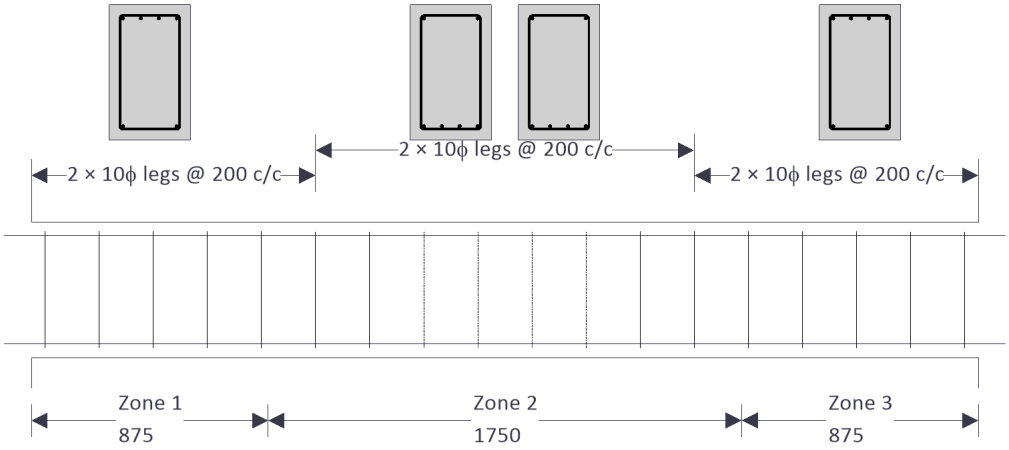
Bottom bar clear spacing — $s_{bot} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s3\_z3\_v}) + \phi_{m1\_s3\_z3\_b\_L1} \times N_{m1\_s3\_z3\_b\_L1})) / (N_{m1\_s3\_z3\_b\_L1} - 1) =$ **186** mm

Min. allowable bottom bar clear spacing (cl.25.2.1) — $s_{bot,min} =$ **25** mm

*PASS - Actual bar spacing exceeds minimum allowable*

**Shear design**




**Rectangular section in shear**

Concrete weight modification factor — $\lambda =$ **1.00**

Location where min. reinf. is req'd ($V_u$ less $\phi V_c$) — Between 924 mm and 2474 mm

Location where no reinf. is req'd ($V_u$ less $\phi V_c$ / 2) — Between 1311 mm and 2086 mm

Maximum reinforcement shear strength — $\phi V_{s,max} = \phi_s \times 8$ psi $\times \sqrt{(\min(f'_c, 10000\text{psi}) / 1\text{ psi})} \times b \times d =$ **300.2** kN

| | |
|---|---|
| Minimum area of shear reinf. (Table 9.6.3.4) | $A_{sv,min}$ = max(50 psi, 0.75 psi × √(f'c / 1 psi)) × b / min($f_y$, 60000 psi) = **250** $mm^2/m$ |

**Zone 1**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**449** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s$ = min(√(2 / (1 + (d / 1 in) / 10)), 1.0) = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **507** $mm^2$ |
| Ratio of longitudinal reinforcement | $\rho_w = A_{st} / (b \times d)$ = **0.004** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c = \phi_s \times \min(8 \times \lambda \times (\rho_w)^{1/3}, 5 \times \lambda) \times \sqrt{f'_c \times 1\ psi} \times b \times d$ = **46.7** kN |
| Design shear force at 449mm from support | $V_u$ = **75.3** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s = \max(V_u - \phi V_c, 0\ kips)$ = **28.6** kN |
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des} = \phi V_s / (\phi_s \times \min(f_y, 60000\ psi) \times d)$ = **205** $mm^2/m$ |
| Area of shear reinforcement required | $A_{sv,req} = \max(A_{sv,min}, A_{sv,des})$ = **250** $mm^2/m$ |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |
| Area of shear reinforcement provided | $A_{sv,prov}$ = **713** $mm^2/m$ |
| | *PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required* |
| Maximum longitudinal spacing (Table 9.7.6.2.2) | $s_{vl,max}$ = d / 2 = **224.6** mm |
| | *PASS - longitudinal spacing of stirrups is less than the maximum allowable* |

**Zone 2**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**449** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s$ = min(√(2 / (1 + (d / 1 in) / 10)), 1.0) = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **507** $mm^2$ |
| Ratio of longitudinal reinforcement | $\rho_w = A_{st} / (b \times d)$ = **0.004** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c = \phi_s \times \min(8 \times \lambda \times (\rho_w)^{1/3}, 5 \times \lambda) \times \sqrt{f'_c \times 1\ psi} \times b \times d$ = **46.7** kN |
| Design shear force within zone | $V_u$ = **58.3** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s = \max(V_u - \phi V_c, 0\ kips)$ = **11.6** kN |
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des} = \phi V_s / (\phi_s \times \min(f_y, 60000\ psi) \times d)$ = **83** $mm^2/m$ |
| Area of shear reinforcement required | $A_{sv,req} = \max(A_{sv,min}, A_{sv,des})$ = **250** $mm^2/m$ |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |
| Area of shear reinforcement provided | $A_{sv,prov}$ = **713** $mm^2/m$ |
| | *PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required* |
| Maximum longitudinal spacing (Table 9.7.6.2.2) | $s_{vl,max}$ = d / 2 = **224.6** mm |
| | *PASS - longitudinal spacing of stirrups is less than the maximum allowable* |

**Zone 3**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**449** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s$ = min(√(2 / (1 + (d / 1 in) / 10)), 1.0) = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **507** $mm^2$ |
| Ratio of longitudinal reinforcement | $\rho_w = A_{st} / (b \times d)$ = **0.004** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c = \phi_s \times \min(8 \times \lambda \times (\rho_w)^{1/3}, 5 \times \lambda) \times \sqrt{f'_c \times 1\ psi} \times b \times d$ = **46.7** kN |
| Design shear force at 449mm from support | $V_u$ = **84.0** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s = \max(V_u - \phi V_c, 0\ kips)$ = **37.3** kN |
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des} = \phi V_s / (\phi_s \times \min(f_y, 60000\ psi) \times d)$ = **268** $mm^2/m$ |
| Area of shear reinforcement required | $A_{sv,req} = \max(A_{sv,min}, A_{sv,des})$ = **268** $mm^2/m$ |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |

Area of shear reinforcement provided $A_{sv,prov}$ = **713** mm²/m

*PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required*

Maximum longitudinal spacing (Table 9.7.6.2.2) $s_{vl,max}$ = d / 2 = **224.6** mm

*PASS - longitudinal spacing of stirrups is less than the maximum allowable*

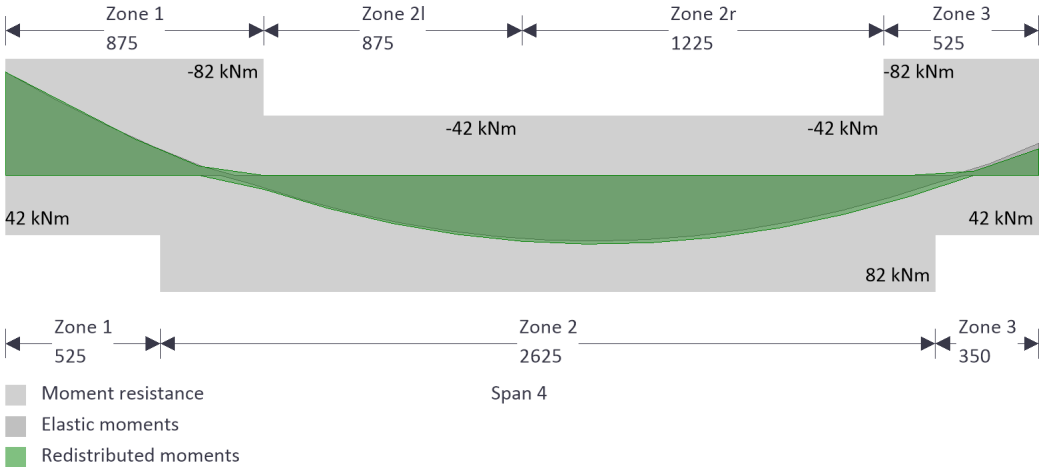
## Beam 1 - Span 4

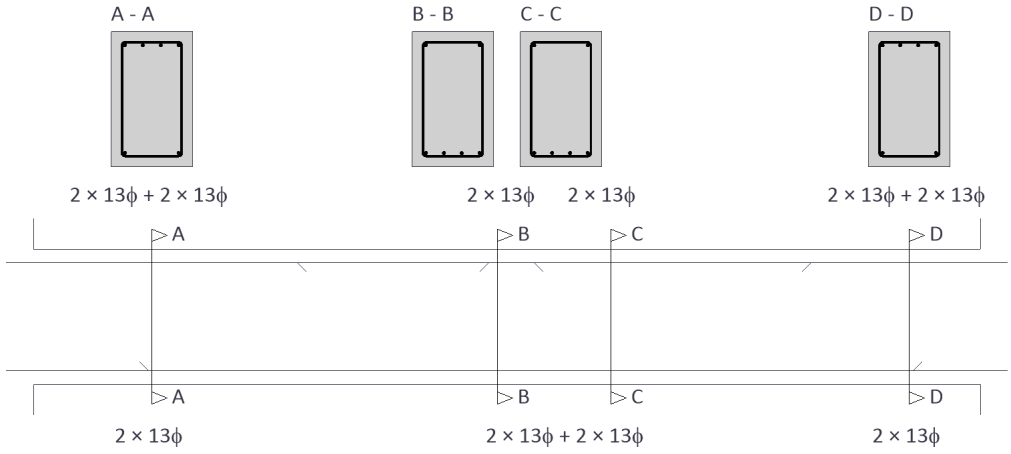
### Rectangular section details

Section width b = **300** mm

Section depth h = **500** mm

### Moment design




### Zone 1 - Negative moment. Rectangular section in flexure (Section 9.5.2)

Factored bending moment at section $M_u$ = abs($M_{m1\_s4\_z1\_min\_red}$) = **72.88** kNm

Effective depth to tension reinforcement d = **449.1** mm

Tension reinforcement provided 2 × 13ϕ + 2 × 13ϕ

Area of tension reinforcement provided $A_{s,prov}$ = **507** mm²

Minimum area of reinforcement (cl.9.6.1.2) $A_{s,min}$ = max(3 psi × √(f'c / 1 psi), 200 psi) × b × d / $f_y$ = **442** mm²

*PASS - Area of reinforcement provided is greater than minimum area of reinforcement required*

Stress block depth factor (cl.22.2.2.4.3) $\beta_1$ = min(max(0.85 - 0.05 × (f'c - 4 ksi) / 1 ksi, 0.65), 0.85) = **0.85**

| | |
|---|---|
| Depth of equivalent rectangular stress block | $a = A_{s,prov} \times f_y / (0.85 \times f'_c \times b)$ = **42** mm |
| Depth to neutral axis | $c = a / \beta_1$ = **49** mm |
| Net tensile strain in extreme tension fibers | $\varepsilon_t = 0.003 \times (d_o - c) / \max(c, 0.001\text{ in})$ = **0.02445** |
| | *Net tensile strain in tension controlled zone* |
| Strength reduction factor (cl.21.2.1) | $\phi_f = \min(\max(0.65 + 0.25 \times (\varepsilon_t - \varepsilon_{ty}) / (0.003), 0.65), 0.9)$ = **0.90** |
| Nominal moment strength | $M_n = A_{s,prov} \times f_y \times (d - a / 2)$ = **91.1** kNm |
| Design moment strength | $\phi M_n = M_n \times \phi_f$ = **82.0** kNm |
| | *PASS - Required moment strength is less than design moment strength* |

**Flexural cracking**

| | |
|---|---|
| Max. center to center spacing of tension reinf. | $s_{t,max} = s_{top} + \phi_{m1\_s4\_z1\_t\_L1}$ = **66** mm |
| Service load stress in reinforcement (cl.24.3.2) | $f_s = 2/3 \times f_y$ = **280** N/mm$^2$ |
| Clear cover of reinforcement | $c_c = c_{nom\_t} + \phi_v$ = **45** mm |
| Maximum allowable top bar spacing (Table 24.3.2) | $s_{max} = \min(15\text{in} \times 40000\text{psi} / f_s - 2.5 \times c_c, 12\text{in} \times 40000\text{psi} / f_s)$ = **264** mm |
| | *PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing* |

**Spacing limits for reinforcement**

| | |
|---|---|
| Top bar clear spacing | $s_{top} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s4\_z1\_v}) + \phi_{m1\_s4\_z1\_t\_L1} \times N_{m1\_s4\_z1\_t\_L1} + \phi_{m1\_s4\_z2l\_t\_L1} \times N_{m1\_s4\_z2l\_t\_L1})) / ((N_{m1\_s4\_z1\_t\_L1} + N_{m1\_s4\_z2l\_t\_L1}) - 1)$ = **53** mm |
| Min. allowable top bar clear spacing (cl.25.2.1) | $s_{top,min}$ = **25** mm |
| Bottom bar clear spacing | $s_{bot} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s4\_z1\_v}) + \phi_{m1\_s4\_z1\_b\_L1} \times N_{m1\_s4\_z1\_b\_L1})) / (N_{m1\_s4\_z1\_b\_L1} - 1)$ = **186** mm |
| Min. allowable bottom bar clear spacing (cl.25.2.1) | $s_{bot,min}$ = **25** mm |
| | *PASS - Actual bar spacing exceeds minimum allowable* |

**Zone 2 - Positive moment. Rectangular section in flexure (Section 9.5.2)**

| | |
|---|---|
| Factored bending moment at section | $M_u = \text{abs}(M_{m1\_s4\_z2\_max\_red})$ = **48.42** kNm |
| Effective depth to tension reinforcement | d = **449.1** mm |
| Tension reinforcement provided | 2 × 13$\phi$ + 2 × 13$\phi$ |
| Area of tension reinforcement provided | $A_{s,prov}$ = **507** mm$^2$ |
| Minimum area of reinforcement (cl.9.6.1.2) | $A_{s,min} = \min(\max(3\text{ psi} \times \sqrt{(f'_c / 1\text{ psi})}, 200\text{ psi}) \times b \times d / f_y, 4/3 \times A_{s,des})$ = **389** mm$^2$ |
| | *PASS - Area of reinforcement provided is greater than minimum area of reinforcement required* |
| Stress block depth factor (cl.22.2.2.4.3) | $\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4\text{ ksi}) / 1\text{ ksi}, 0.65), 0.85)$ = **0.85** |
| Depth of equivalent rectangular stress block | $a = A_{s,prov} \times f_y / (0.85 \times f'_c \times b)$ = **42** mm |
| Depth to neutral axis | $c = a / \beta_1$ = **49** mm |
| Net tensile strain in extreme tension fibers | $\varepsilon_t = 0.003 \times (d_o - c) / \max(c, 0.001\text{ in})$ = **0.02445** |
| | *Net tensile strain in tension controlled zone* |
| Strength reduction factor (cl.21.2.1) | $\phi_f = \min(\max(0.65 + 0.25 \times (\varepsilon_t - \varepsilon_{ty}) / (0.003), 0.65), 0.9)$ = **0.90** |
| Nominal moment strength | $M_n = A_{s,prov} \times f_y \times (d - a / 2)$ = **91.1** kNm |
| Design moment strength | $\phi M_n = M_n \times \phi_f$ = **82.0** kNm |
| | *PASS - Required moment strength is less than design moment strength* |

**Flexural cracking**

| | |
|---|---|
| Max. center to center spacing of tension reinf. | $s_{b,max} = s_{bot} + \phi_{m1\_s4\_z2\_b\_L1}$ = **66** mm |
| Service load stress in reinforcement (cl.24.3.2) | $f_s = 2/3 \times f_y$ = **280** N/mm$^2$ |

| | |
|---|---|
| Clear cover of reinforcement | $c_c = c_{nom\_b} + \phi_v$ = **45** mm |
| Maximum allowable bot bar spacing (Table 24.3.2) | $s_{max} = \min(15in \times 40000psi / f_s - 2.5 \times c_c, 12in \times 40000psi / f_s)$ = **264** mm |

*PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing*

**Control of deflections (Section 24.2)**

| | |
|---|---|
| Concrete density factor | $K_w$ = **1.00** |
| Reinforcement yield strength factor | $K_f = 0.4 + f_y / 100000$ psi = **1.01** |
| Minimum thickness of beam (Table 9.3.1.1) | $h_{min} = (L_{m1\_s4} / 18.5) \times K_w \times K_f$ = **191** mm |

*PASS - Thickness of beam exceeds minimum thickness*

**Spacing limits for reinforcement**

| | |
|---|---|
| Top bar clear spacing | $s_{top} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s4\_z2\_v}) + \phi_{m1\_s4\_z2r\_t\_L1} \times N_{m1\_s4\_z2r\_t\_L1})) / (N_{m1\_s4\_z2r\_t\_L1} - 1)$ = **186** mm |
| Min. allowable top bar clear spacing (cl.25.2.1) | $s_{top,min}$ = **25** mm |
| Bottom bar clear spacing | $s_{bot} = (b - (2 \times (c_{nom\_s} + \phi_{m1\_s4\_z2\_v}) + \phi_{m1\_s4\_z2\_b\_L1} \times N_{m1\_s4\_z2\_b\_L1} + \phi_{m1\_s4\_z1\_b\_L1} \times N_{m1\_s4\_z1\_b\_L1})) / ((N_{m1\_s4\_z2\_b\_L1} + N_{m1\_s4\_z1\_b\_L1}) - 1)$ = **53** mm |
| Min. allowable bottom bar clear spacing (cl.25.2.1) | $s_{bot,min}$ = **25** mm |

*PASS - Actual bar spacing exceeds minimum allowable*

**Zone 3 - Positive moment. Rectangular section in flexure (Section 9.5.2)**

| | |
|---|---|
| Factored bending moment at section | $M_u = abs(M_{m1\_s4\_z3\_max\_red})$ = **9.07** kNm |
| Effective depth to tension reinforcement | d = **449.1** mm |
| Tension reinforcement provided | 2 × 13$\phi$ |
| Area of tension reinforcement provided | $A_{s,prov}$ = **253** mm$^2$ |
| Minimum area of reinforcement (cl.9.6.1.2) | $A_{s,min} = \min(\max(3 psi \times \sqrt{(f'_c / 1 psi)}, 200 psi) \times b \times d / f_y, 4/3 \times A_{s,des})$ = **72** mm$^2$ |

*PASS - Area of reinforcement provided is greater than minimum area of reinforcement required*

| | |
|---|---|
| Stress block depth factor (cl.22.2.2.4.3) | $\beta_1 = \min(\max(0.85 - 0.05 \times (f'_c - 4 ksi) / 1 ksi, 0.65), 0.85)$ = **0.85** |
| Depth of equivalent rectangular stress block | $a = A_{s,prov} \times f_y / (0.85 \times f'_c \times b)$ = **21** mm |
| Depth to neutral axis | $c = a / \beta_1$ = **25** mm |
| Net tensile strain in extreme tension fibers | $\varepsilon_t = 0.003 \times (d_o - c) / \max(c, 0.001 in)$ = **0.05189** |

*Net tensile strain in tension controlled zone*

| | |
|---|---|
| Strength reduction factor (cl.21.2.1) | $\phi_f = \min(\max(0.65 + 0.25 \times (\varepsilon_t - \varepsilon_{ty}) / (0.003), 0.65), 0.9)$ = **0.90** |
| Nominal moment strength | $M_n = A_{s,prov} \times f_y \times (d - a / 2)$ = **46.7** kNm |
| Design moment strength | $\phi M_n = M_n \times \phi_f$ = **42.0** kNm |

*PASS - Required moment strength is less than design moment strength*

**Flexural cracking**

| | |
|---|---|
| Max. center to center spacing of tension reinf. | $s_{b,max} = s_{bot} + \phi_{m1\_s4\_z3\_b\_L1}$ = **198** mm |
| Service load stress in reinforcement (cl.24.3.2) | $f_s = 2/3 \times f_y$ = **280** N/mm$^2$ |
| Clear cover of reinforcement | $c_c = c_{nom\_b} + \phi_v$ = **45** mm |
| Maximum allowable bot bar spacing (Table 24.3.2) | $s_{max} = \min(15in \times 40000psi / f_s - 2.5 \times c_c, 12in \times 40000psi / f_s)$ = **264** mm |

*PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing*

**Zone 3 - Negative moment. Rectangular section in flexure (Section 9.5.2)**

| | |
|---|---|
| Factored bending moment at section | $M_u = abs(M_{m1\_s4\_z3\_min\_red})$ = **18.72** kNm |
| Effective depth to tension reinforcement | d = **449.1** mm |

| | |
|---|---|
| Tension reinforcement provided | $2 \times 13\phi + 2 \times 13\phi$ |
| Area of tension reinforcement provided | $A_{s,prov}$ = **507** mm$^2$ |
| Minimum area of reinforcement (cl.9.6.1.2) | $A_{s,min}$ = min(max(3 psi × √(f'$_c$ / 1 psi), 200 psi) × b × d / $f_y$, 4/3 × $A_{s,des}$) = **148** mm$^2$ |
| | *PASS - Area of reinforcement provided is greater than minimum area of reinforcement required* |
| Stress block depth factor (cl.22.2.2.4.3) | $\beta_1$ = min(max(0.85 - 0.05 × (f'$_c$ - 4 ksi) / 1 ksi, 0.65), 0.85) = **0.85** |
| Depth of equivalent rectangular stress block | a = $A_{s,prov}$ × $f_y$ / (0.85 × f'$_c$ × b) = **42** mm |
| Depth to neutral axis | c = a / $\beta_1$ = **49** mm |
| Net tensile strain in extreme tension fibers | $\varepsilon_t$ = 0.003 × ($d_o$ - c) / max(c, 0.001 in) = **0.02445** |
| | *Net tensile strain in tension controlled zone* |
| Strength reduction factor (cl.21.2.1) | $\phi_f$ = min(max(0.65 + 0.25 × ($\varepsilon_t$ - $\varepsilon_{ty}$) / (0.003), 0.65), 0.9) = **0.90** |
| Nominal moment strength | $M_n$ = $A_{s,prov}$ × $f_y$ × (d - a / 2) = **91.1** kNm |
| Design moment strength | $\phi M_n$ = $M_n$ × $\phi_f$ = **82.0** kNm |
| | *PASS - Required moment strength is less than design moment strength* |

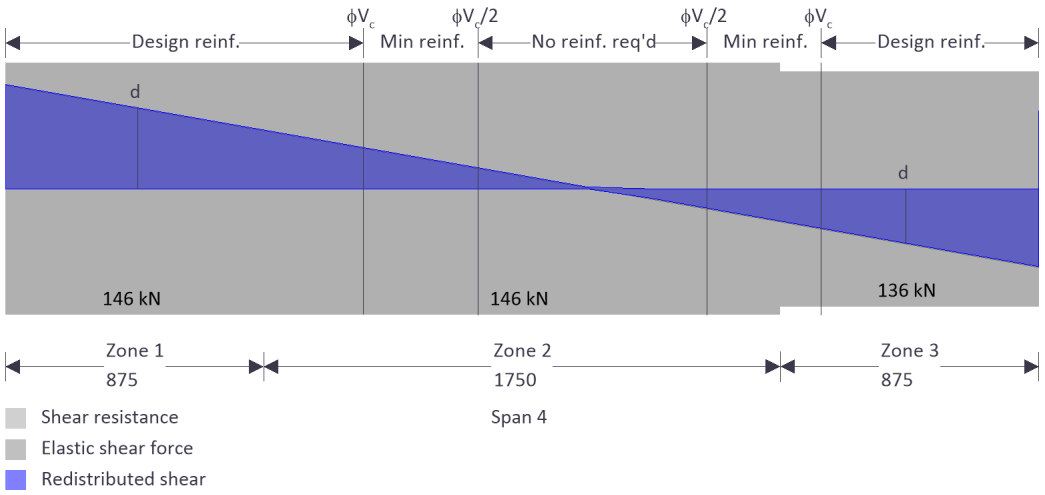
**Flexural cracking**

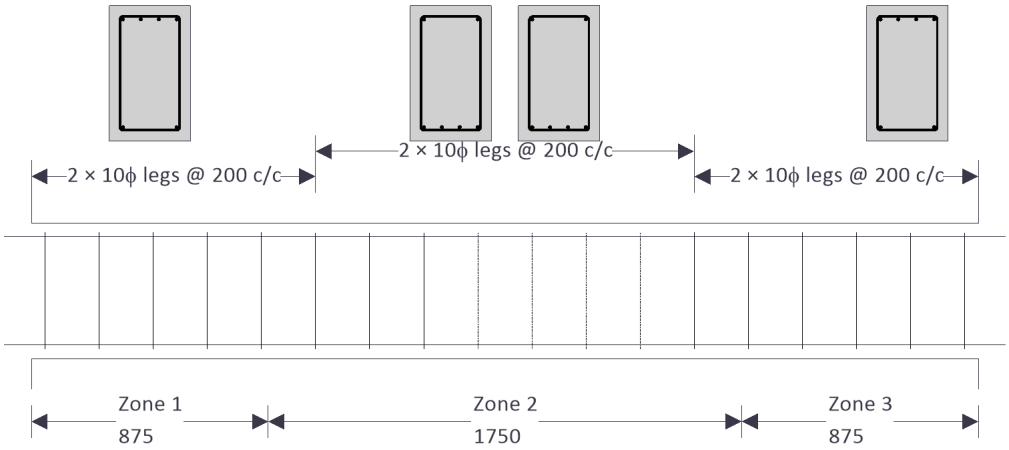
| | |
|---|---|
| Max. center to center spacing of tension reinf. | $s_{t,max}$ = $s_{top}$ + $\phi_{m1\_s4\_z3\_t\_L1}$ = **66** mm |
| Service load stress in reinforcement (cl.24.3.2) | $f_s$ = 2/3 × $f_y$ = **280** N/mm$^2$ |
| Clear cover of reinforcement | $c_c$ = $c_{nom\_t}$ + $\phi_v$ = **45** mm |
| Maximum allowable top bar spacing (Table 24.3.2) | $s_{max}$ = min(15in × 40000psi / $f_s$ - 2.5 × $c_c$, 12in × 40000psi / $f_s$) = **264** mm |
| | *PASS - Maximum allowable tension reinforcement spacing exceeds actual spacing* |

**Spacing limits for reinforcement**

| | |
|---|---|
| Top bar clear spacing | $s_{top}$ = (b - (2 × ($c_{nom\_s}$ + $\phi_{m1\_s4\_z3\_v}$) + $\phi_{m1\_s4\_z3\_t\_L1}$ × $N_{m1\_s4\_z3\_t\_L1}$ + $\phi_{m1\_s4\_z2r\_t\_L1}$ × $N_{m1\_s4\_z2r\_t\_L1}$)) / (($N_{m1\_s4\_z3\_t\_L1}$ + $N_{m1\_s4\_z2r\_t\_L1}$) - 1) = **53** mm |
| Min. allowable top bar clear spacing (cl.25.2.1) | $s_{top,min}$ = **25** mm |
| Bottom bar clear spacing | $s_{bot}$ = (b - (2 × ($c_{nom\_s}$ + $\phi_{m1\_s4\_z3\_v}$) + $\phi_{m1\_s4\_z3\_b\_L1}$ × $N_{m1\_s4\_z3\_b\_L1}$)) / ($N_{m1\_s4\_z3\_b\_L1}$ - 1) = **186** mm |
| Min. allowable bottom bar clear spacing (cl.25.2.1) | $s_{bot,min}$ = **25** mm |
| | *PASS - Actual bar spacing exceeds minimum allowable* |

**Shear design**






**Rectangular section in shear**

| | |
|---|---|
| Concrete weight modification factor | $\lambda$ = **1.00** |
| Location where min. reinf. is req'd ($V_u$ less $\phi V_c$) | Between 1213 mm and 2763 mm |
| Location where no reinf. is req'd ($V_u$ less $\phi V_c$ / 2) | Between 1601 mm and 2376 mm |
| Maximum reinforcement shear strength | $\phi V_{s,max} = \phi_s \times 8$ psi $\times \sqrt{(\min(f'_c, 10000\text{psi}) / 1\text{ psi})} \times b \times d$ = **300.2** kN |
| Minimum area of shear reinf. (Table 9.6.3.4) | $A_{sv,min} = \max(50\text{ psi}, 0.75\text{ psi} \times \sqrt{(f'_c / 1\text{ psi})} \times b / \min(f_y, 60000\text{ psi})$ = **250** mm²/m |

**Zone 1**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**449** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s = \min(\sqrt{(2 / (1 + (d / 1\text{ in}) / 10))}, 1.0)$ = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **507** mm² |
| Ratio of longitudinal reinforcement | $\rho_w = A_{st} / (b \times d)$ = **0.004** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c = \phi_s \times \min(8 \times \lambda \times (\rho_w)^{1/3}, 5 \times \lambda) \times \sqrt{(f'_c \times 1\text{ psi})} \times b \times d$ = **46.7** kN |
| Design shear force at 449mm from support | $V_u$ = **93.8** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s = \max(V_u - \phi V_c, 0\text{ kips})$ = **47.2** kN |
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des} = \phi V_s / (\phi_s \times \min(f_y, 60000\text{ psi}) \times d)$ = **338** mm²/m |
| Area of shear reinforcement required | $A_{sv,req} = \max(A_{sv,min}, A_{sv,des})$ = **338** mm²/m |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |
| Area of shear reinforcement provided | $A_{sv,prov}$ = **713** mm²/m |

*PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required*

| | |
|---|---|
| Maximum longitudinal spacing (Table 9.7.6.2.2) | $s_{vl,max} = d / 2$ = **224.6** mm |

*PASS - longitudinal spacing of stirrups is less than the maximum allowable*

**Zone 2**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**449** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s = \min(\sqrt{(2 / (1 + (d / 1\text{ in}) / 10))}, 1.0)$ = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **507** mm² |
| Ratio of longitudinal reinforcement | $\rho_w = A_{st} / (b \times d)$ = **0.004** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c = \phi_s \times \min(8 \times \lambda \times (\rho_w)^{1/3}, 5 \times \lambda) \times \sqrt{(f'_c \times 1\text{ psi})} \times b \times d$ = **46.7** kN |
| Design shear force within zone | $V_u$ = **68.2** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s = \max(V_u - \phi V_c, 0\text{ kips})$ = **21.5** kN |

| | |
|---|---|
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des} = \phi V_s / (\phi_s \times \min(f_y, 60000\ psi) \times d)$ = **154** $mm^2/m$ |
| Area of shear reinforcement required | $A_{sv,req} = \max(A_{sv,min}, A_{sv,des})$ = **250** $mm^2/m$ |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |
| Area of shear reinforcement provided | $A_{sv,prov}$ = **713** $mm^2/m$ |

*PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required*

| | |
|---|---|
| Maximum longitudinal spacing (Table 9.7.6.2.2) | $s_{vl,max}$ = d / 2 = **224.6** mm |

*PASS - longitudinal spacing of stirrups is less than the maximum allowable*

**Zone 3**

| | |
|---|---|
| Effective depth of long. reinf. used for shear zone | d =**449** mm |
| Size effect factor (cl. 22.5.5.1.3) | $\lambda_s = \min(\sqrt{(2 / (1 + (d / 1\ in) / 10))}, 1.0)$ = **0.85** |
| Area of longitudinal reinforcement | $A_{st}$ = **253** $mm^2$ |
| Ratio of longitudinal reinforcement | $\rho_w = A_{st} / (b \times d)$ = **0.002** |
| Concrete shear strength (Table 22.5.5.1) | $\phi V_c = \phi_s \times \min(8 \times \lambda \times (\rho_w)^{1/3}, 5 \times \lambda) \times \sqrt{(f'_c \times 1\ psi)} \times b \times d$ = **37.1** kN |
| Design shear force at 449mm from support | $V_u$ = **64.0** kN |
| Reinf. shear strength required (eqn. 22.5.1.1) | $\phi V_s = \max(V_u - \phi V_c, 0\ kips)$ = **26.9** kN |
| Area of design shear reinf. req'd (eqn. 22.5.8.5.3) | $A_{sv,des} = \phi V_s / (\phi_s \times \min(f_y, 60000\ psi) \times d)$ = **193** $mm^2/m$ |
| Area of shear reinforcement required | $A_{sv,req} = \max(A_{sv,min}, A_{sv,des})$ = **250** $mm^2/m$ |
| Shear reinforcement provided | 2 × 10ϕ legs @ 200 c/c |
| Area of shear reinforcement provided | $A_{sv,prov}$ = **713** $mm^2/m$ |

*PASS - Area of shear reinforcement provided exceeds area of shear reinforcement required*

| | |
|---|---|
| Maximum longitudinal spacing (Table 9.7.6.2.2) | $s_{vl,max}$ = d / 2 = **224.6** mm |

*PASS - longitudinal spacing of stirrups is less than the maximum allowable*